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TECHNICAL AND COST ASSESSMENTS OF POTENTIAL CONTROL OPTIONS FOR TRS EMISSIONS FROM ONTARIO SOURCES

Final Report

OCTOBER 1995

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Final Report

TECHNICAL AND COST ASSESSMENTS OF POTENTIAL CONTROL OPTIONS FOR TRS EMISSIONS FROM ONTARIO SOURCES

Prepared for:

Ontario Ministry of Environment and Energy

Prepared by:

SENES Consultants Limited

Eugene Koczkur, Ph.D., P.Eng.
Chairman

Chris C. Marson, P.Eng.
Senior Environmental Engineer

Jennifer L. Kirkaldy, B.A.Sc.
Environmental Engineer

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EXECUTIVE SUMMARY

SENES Consultants Limited was commissioned by the Ontario Ministry of Environment and Energy (MOEE) to assess the technical feasibility and associated costs of different options for controlling total reduced sulphur (TRS) emissions from Ontario sources. The overall goal of the study was to use up-to-date engineering information to determine the benefits and costs of various control options. The information was prepared to allow the MOEE to assess the implications of reducing the interim standards for TRS and its compounds.

The MOEE identified Kraft pulp mills, steel mills and silicon carbide abrasive manufacturing as the three industry sectors to be considered. This study provides detailed source information for three pulp mills (Rainy River Forest Products Inc., formerly Boise Cascade in Fort Frances; Malette in Smooth Rock Falls and Domtar Packaging in Red Rock), two steel mills (Stelco-Hilton Works and Dofasco in Hamilton) and one abrasives manufacturer (Treibacher Schleifmittel in Niagara Falls).

The first task was to prepare an emission inventory for each of the six facilities. Process details were gathered from the facilities and the MOEE files. The existing control equipment for each of the TRS emission locations was documented for each of the facilities.

The second task was the identification of the available control options for each of the process emission sources using available literature and other sources. The TRS removal efficiency of each of the control options was also documented.

The third task involved calculating the costs for generic control equipment using standard cost evaluation techniques. Annualized costs which include operating and maintenance costs and capital costs distributed over a 10-year period, were developed. Where possible, the cost per tonne of TRS removed was calculated. For facilities where sufficient information was available, the costs for various control options were evaluated using generic cost algorithms. These costs are estimated to be within -25% to +75% of the actual costs.

The main difficulty encountered in this project was a lack of information. TRS emissions from the pulp industry have been studied extensively whereas little information is available on TRS emissions from steel plants where the focus has been on particulates, and oxides of nitrogen and

sulphur. The silicon carbide abrasive manufacturing process studied is a unique facility, and very little information was available on TRS emissions from abrasives manufacturing and emissions controls.

The emission inventories for TRS were relatively complete for the pulp mill sector but not necessarily consistent from mill to mill. The TRS emission inventories for the steel mills are not very well defined. The emissions from the abrasive manufacturing are based on a single set of stack tests.

Pulp Mills

The lime kiln and the recovery boiler are generally the largest emitters of TRS (on a mass basis) but since their emissions are discharged from tall stacks, their contributions to ground level concentrations may be relatively small. TRS emissions from smelt dissolving tanks and the brownstock washers are discharged through short stacks and, therefore, may contribute significantly more to the ground level concentrations.

The annualized costs developed range from $41,000 for the incineration of emissions from a condensate stripper to $17,681,000 for conversion to a low odour recovery boiler. The cost effectiveness for removal of TRS on an annual basis ranges from $200/t for the incineration of the exhausts from a condensate stripper to $107,000/t for control of the black liquor oxidation vents. Estimated annualized costs for specific mills range from $1,000,000/year to $8,000,000/year to control TRS emission levels off property to 5 $\mu g/m^3$ (1/2 hour average).

Steel Mills

From the limited TRS emission data available, it appears that the greatest source of TRS emissions is the slag processing operation. There are very limited control options available. The annualized cost for a scrubber was estimated to be $3,613,000/year. The coke oven battery is a relatively minor source of TRS emissions at a steel mill. A costing methodology for coke oven batteries is presented but the two facilities studied appear to have emissions that are below the lower limits of the cost function. The coke oven gas by-products plant is a potential source of TRS emissions but limited data is available on TRS emissions.

Abrasives Manufacturing

For the abrasive manufacturer studied, TRS is emitted from a tall stack and there are fugitive leaks from the domes enclosing the process. Ambient levels of TRS could be reduced with a taller stack to increase dispersion. Add-on control options are a scrubber and an incinerator. A process change to the use of a lower sulphur petroleum coke would also result in lower TRS emissions both from the stack and fugitive sources. The cost effectiveness for TRS removal on an annual basis ranges from $3,300/t for lower sulphur coke to $12,000/t for a scrubber.

In general, better characterization of TRS emissions are needed for all sectors, especially for the steel mills and abrasive manufacturers.

The actual costs that each facility will incur depend on the relative position of the facility with respect to the property line. Facilities that are built close to their property line will require more control and incur greater costs to meet a lower point-of-impingement standard for TRS.

TABLE OF CONTENTS

Page No.

ACKNOWLEDGEMENTS

1.0 INTRODUCTION 1-1

2.0 INFORMATION SOURCES 2-1
2.1 Ontario Ministry of Environment and Energy Files 2-1
2.2 Facility Supplied Information 2-2
2.3 United States Environmental Protection Agency (U.S. EPA) 2-2
2.4 Publications 2-3
2.5 Other Sources 2-3

3.0 CONTROL TECHNOLOGIES - KRAFT PULP MILLS 3-1
3.1 TRS Compounds 3-1
3.1.1 Hydrogen Sulphide 3-1
3.1.2 Methyl Mercaptan 3-2
3.1.3 Dimethyl Sulphide 3-2
3.1.4 Dimethyl Disulphide 3-2
3.2 Emission Points 3-3
3.2.1 Digester System 3-3
3.2.2 Brownstock Washer System 3-4
3.2.3 Pulp Bleaching 3-6
3.2.4 Black Liquor Oxidation 3-6
3.2.5 Multiple-Effect Evaporator System 3-7
3.2.6 Tall Oil Plant 3-9
3.2.7 Recovery Boiler 3-9
3.2.8 Smelt Dissolving Tank 3-11
3.2.9 Lime Mud Washing 3-13
3.2.10 Lime Kiln 3-15
3.2.11 Scrubbers 3-16
3.2.11.1 Recovery Boiler Scrubbers 3-17
3.2.11.2 Smelt Dissolving Tank Scrubbers 3-18
3.2.11.3 Lime Kiln Scrubbers 3-18

TABLE OF CONTENTS
(Continued)

Page No.

3.2.12 Condensate Stripping 3-19
3.2.13 Vent Sources 3-19
3.2.13.1 Existing Combustion Devices 3-20
3.2.13.2 Thermal and Catalytic Incineration 3-23
3.2.13.3 Alternative Controls 3-24
3.2.14 Fugitive Emissions 3-24
3.3 Regulatory Approaches to Controlling TRS Emissions 3-25
3.3.1 U.S. EPA Approach - Mass Emission Reduction - Large Sources . 3-25
3.3.2 U.S. EPA Approach - Mass Emission Reduction - Small Sources . 3-26
3.3.3 Ontario Regulation 346 3-30
3.4 TRS Emissions Controls at Pulp Mills 3-31
3.4.1 Rainy River Forest Products Inc. - Fort Frances 3-31
3.4.2 Malette - Smooth Rock Falls 3-35
3.4.3 Domtar Packaging - Red Rock 3-37
3.5 Generic Costs of TRS Control Options 3-41
3.5.1 Recovery Boiler 3-42
3.5.2 Black Liquor Oxidation 3-43
3.5.3 Lime Kiln Process Control 3-44
3.5.4 Lime Mud Washing 3-45
3.5.5 Scrubbers 3-46
3.5.6 Brownstock Washers 3-48
3.5.7 Ductwork and Enclosures Costs 3-48
3.5.8 Thermal Incinerator 3-51
3.5.9 Steam Strippers 3-52
3.5.10 Summary Costs 3-53
3.5.11 Rainy River Forest Products Inc. 3-57
3.5.12 Malette Pulp and Power 3-58
3.5.13 Domtar Packaging 3-60

TABLE OF CONTENTS
(Continued)

Page No.

4.0 IRON AND STEEL INDUSTRY 4-1
4.1 Sources 4-1
4.1.1 Coke Oven Batteries 4-2
4.1.1.1 By-Product Coke Production 4-5
4.1.1.2 Non-Recovery Battery Coke Production 4-8
4.1.2 Blast Furnace 4-9
4.1.3 Steel Production 4-10
4.2 Controls 4-11
4.2.1 Coke Oven Batteries 4-11
4.2.1.1 By-Product Coke Production 4-11
4.2.1.2 Non-Recovery Battery Coke Production 4-16
4.2.2 Blast Furnace 4-16
4.2.3 Steel Manufacturing 4-18
4.3 Steel Mills in Ontario 4-18
4.3.1 Stelco - Hilton Works Coke Ovens 4-18
4.3.2 Stelco Slag Processing 4-20
4.3.3 Dofasco Coke Ovens 4-21
4.3.4 Dofasco Slag Processing 4-23
4.4 Costs 4-23
4.4.1 Coke Oven Batteries 4-23
4.4.2 Slag Processing 4-24

5.0 SILICON CARBIDE ABRASIVE MANUFACTURE 5-1
5.1 Silicon Carbide Manufacture 5-1
5.2 Treibacher Schleifmittel 5-1
5.2.1 Plant Operation 5-1
5.2.2 H_2S Emissions 5-3
5.2.2.1 Emission Rate Estimates 5-3
5.2.3 H_2S Emissions Controls in the Silicon Carbide Industry 5-4
5.2.4 H_2S Emissions Controls and Costs at Treibacher 5-5

TABLE OF CONTENTS
(Continued)

Page No.

6.0 CONCLUSIONS AND RECOMMENDATIONS 6-1
6.1 Pulp Mills 6-1
6.2 Steel Mills 6-2
6.3 Treibacher Schleifmittel 6-3

REFERENCES R-1

ABBREVIATIONS I

GLOSSARY IV

APPENDIX A: EQUIPMENT SUPPLIERS
APPENDIX B: PULP MILL DISPERSION MODELLING DETAILS
APPENDIX C: DETAILED CONTROL COSTS FOR PULP MILLS
APPENDIX D: MEASURED VISIBLE EMISSIONS AT COKE OVEN BATTERIES IN THE UNITED STATES
APPENDIX E: EXAMPLE COKE OVEN EMISSION CALCULATIONS
APPENDIX F: U.S. EPA 1987 - COSTS FOR COKE OVEN BATTERIES

LIST OF TABLES

		Follows Page No.
3.1	Kraft Pulping Uncontrolled TRS Emission Factors	3-4
3.2	Pulp Mill Emission Factors (Uncontrolled) for Individual Sources and Compounds (U.S. EPA 1993a)	3-4
3.3	RACT/BACT/LAER Summaries - Pulp and Paper TRS/H_2S Emissions	3-6
3.4	U.S. EPA Regulatory Limits	3-27*
3.5	Summary of State Regulations for Emissions From Pulping Facilities	3-29*
3.6	Rainy River Forest Products Inc. (Fort Frances) TRS Emissions (IMET 1992)	3-32
3.7	Malette Kraft Pulp and Power (Smooth Rock Falls) - TRS Emissions (Air Testing Services 1993, 1992)	3-32
3.8	Domtar Packaging - Red Rock Mill TRS Emissions (Domtar 1988)	3-32
3.9	Comparison of Pulp Mill Emissions with U.S. EPA NSPS and Existing Mill Emission Guidelines	3-32
3.10	Reported Capital Costs for Pulp Mill Control Equipment	3-42
3.11	Reported Annualized Costs for Pulp Mill Control Equipment	3-42
3.12	Estimated Capital Costs for Pulp Mill Control Equipment ($CAN 1994)	3-54
3.13	Estimated Annualized Costs for Pulp Mill Control Equipment ($CAN 1994)	3-56
3.14	Estimated Operating and Maintenance Costs for Pulp Mill Control Equipment ($CAN 1994)	3-56
3.15	Estimated Cost Effectiveness for Pulp Mill Control Equipment ($CAN 1994) (1,000 TPD Pulp Mill)	3-56
3.16	Rainy River Forest Products Inc. Control Costs	3-56
3.17	Malette Kraft Pulp and Power Control Costs	3-56
3.18	Domtar Packaging Control Costs	3-56
3.19	Maximum GLC at Rainy River Forest Products	3-56
3.20	Maximum GLC at Domtar Packaging	3-56
4.1	Typical Coke Oven Gas Emissions for a Poorly Controlled Battery	4-4
4.2	U.S. EPA Proposed Coke Oven Emission Standards	4-5*
4.3	Instantaneous Coke Oven Gas Emission Rates for Poorly Controlled Batteries	4-6

4.4 One Hour Average Coke Oven Gas Emission Rates for a Battery Operating at MACT Limits 4-6
4.5 Measured H_2S Emissions from Slag Operations 4-10*
4.6 Estimated Emission Rates from Sources at Stelco 4-19*
4.7 Estimated Emission Rates from Sources at Dofasco 4-22*
4.8 Control Costs for Visible Emissions (U.S. EPA 1987) 4-24
4.9 Slag Operations Scrubber OAQPS Costing Methodology ($Can 1994) 4-25

5.1 ISCST Model Results for Treibacher Schleifmittel 5-4
5.2 Abrasives Manufacture Scrubber OAQPS Costing Methodology ($Can 1994) 5-8
5.3 Abrasives Manufacture Incinerator OAQPS Costing Methodology ($Can 1994) . . 5-8
5.4 Cost Summary for Treibacher Schleifmittel ($Can 1994) 5-8

* Table appears on page number indicated.

LIST OF FIGURES

		Follows Page No.
3.1	Kraft Pulping Process	3-4
4.1	Iron and Steel Industry	4-2
4.2	Charging Emissions - Average Battery	4-6
4.3	Door Leak Emissions - Average Battery	4-6
4.4	Lids and Offtake Emissions - Average Battery	4-6
5.1	Treibacher Schleifmittel Plant Layout	5-4
5.2	Measured TRS Concentrations at Station 27055	5-4
5.3	Station 27055 Niagara Falls	5-4

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1.0 INTRODUCTION

SENES Consultants Limited was commissioned by the Ministry of Environment and Energy (MOEE) to assess the technical feasibility and associated costs of different options for controlling total reduced sulphur (TRS) emissions from Ontario sources. The overall goal of this study was to use up-to-date engineering information to determine the benefits and costs of the control options. The information was prepared to allow the MOEE to assess the implications of reducing the interim standards for TRS and its compounds. The main objectives defined to achieve this goal were as follows:

1. identify key sources of TRS emissions in Ontario and develop a detailed inventory of sources and emissions of TRS and its constituents;

2. identify and examine a full range of available technical possibilities, abatement technologies and programs (combinations of technology) to reduce TRS emissions;

3. generate estimates of TRS removal efficiencies for each technical possibility, technology or program (combination of technologies) and the limits of such estimates; and

4. prepare detailed abatement cost estimates that can be applied within each sector for new and retrofitted TRS controls.

Other pollutants (HAPs, VOCs, NO_x) which are also affected by the TRS control technologies are also discussed.

This study provides detailed source information for three pulp mills (Rainy River Forest Products Inc., formerly Boise Cascade in Fort Frances, Malette in Smooth Rock Falls and Domtar Packaging in Red Rock), two steel mills (Stelco-Hilton Works and Dofasco in Hamilton) and one abrasives manufacturer (Treibacher Schleifmittel in Niagara Falls). The emission reduction alternatives for these sources were evaluated and costing information was developed for each facility.

The results of the work are presented in the following chapters. The data sources used to obtain information are described in Chapter 2. Chapters 3, 4, and 5 give descriptions of TRS emissions, controls and costs for the pulp and paper industry, the steel industry and the abrasives manufacturing industry respectively. Conclusions and recommendations are given in Chapter 6.

2.0 INFORMATION SOURCES

The main sources of information used in the preparation of this report were MOEE files, facility supplied information, U.S. EPA documents, publications, equipment suppliers and team member experience.

2.1 ONTARIO MINISTRY OF ENVIRONMENT AND ENERGY FILES

For the six facilities under study (three kraft mills, two steel mills and one abrasives manufacturer) some site-specific, process related information was obtained from the Approvals Branch, the District offices and the MOEE project team members' files.

Applications for Certificate of Approval (Air) were examined for details on the processes and control equipment currently in place at the facilities under study. These files were of variable usefulness for this study depending on the year of application. Information in these files consisted primarily of descriptions and specifications for new control equipment or changes in process. There was little information on older existing equipment. Source inventories were often incomplete. In some cases, there were Ontario Regulation 346 (O.Reg. 346) modelling results for the new equipment only, but this did not include all of the other sources of TRS from the facility.

The MOEE District Offices were contacted for information in their files. There were source sampling surveys available for several of the facilities under study. These reports had emission rates and details on the stack parameters such as flow rate, temperature and diameter. There was little detail on the process operation and the control equipment in place.

The pulp mills which are discussed in this study were chosen for two main reasons: (1) the availability of a recent emission inventory; and (2) the variability of existing control technologies at the mills.

The MOEE project members supplied SENES with contact names within the MOEE and at the facilities under study.

2.2 Facility Supplied Information

Five facilities agreed to participate in this study and supply information on their operation. For the kraft mills, Rainy River Forest Products Inc., Domtar Packaging and Malette Pulp and Power supplied valuable information on their processes as did Stelco and Dofasco for the iron and steel industry and Treibacher Schleifmittel for the abrasives industry. Information was extracted from references sent to the district MOEE office.

2.3 United States Environmental Protection Agency (U.S. EPA)

The U.S. EPA released a series of publications in late 1993 regarding the air emissions and water discharges from pulp mills in support of pending regulations under the Clean Air Act (U.S. EPA 1993a,b,c,d). These regulations are focused on the removal of hazardous air pollutants (HAP) of which TRS compounds are a subgroup. The U.S. EPA prepared these documents after contacting a number of pulp mills and control equipment suppliers. End-of-pipe control options and process changes are discussed in the publications. The documents are currently under public review and are subject to modification. HAP Regulations are planned to be in place by 1997. Costs were developed by EPA assuming a control-configuration for three different sizes of model mills.

The Clean Air Act dictates several technology-based limitations affecting new or modified air pollution sources. New Source Performance Standards (NSPS) are uniform national standards set by EPA for specific categories of new or modified sources. Major new or modified sources must install either BACT (Best Available Control Technology) or LAER (Lowest Achievable Emission Rate) equipment depending on the location of the source. For areas that are in attainment with the National Ambient Air Quality Standards, BACT is to be applied. For non-attainment areas, LAER equipment is to be applied. Both BACT and LAER are determined on a case-by-case basis. Recently, more state and local air pollution control agencies have assumed responsibility for implementing BACT and LAER.

Information on installed control equipment in the USA was obtained from the RACT[1]/BACT/LAER Clearinghouse database. The purpose of the Clearinghouse is to provide

[1] RACT - Reasonably Achievable Control Technology.

current information on control technology determinations that are made nationwide. The Clearinghouse listings for 1990 to 1993 (U.S. EPA 1990, 1991, 1992, 1993e) were obtained in hard copy and electronic format. Database searches were made to verify recent determinations for the subject industries. Several contacts for each industry were made to obtain additional information on specific installations.

2.4 PUBLICATIONS

Periodicals and text books were reviewed for background information on the processes in use in the subject industries and the TRS control technologies that have been installed.

2.5 OTHER SOURCES

The personal experience and knowledge of the team members for specific industries, their control technologies and costs were used to supplement information obtained from the foregoing sources.

3.0 CONTROL TECHNOLOGIES - KRAFT PULP MILLS

Total Reduced Sulphur (TRS) compounds include hydrogen sulphide, methyl mercaptan, dimethyl sulphide and dimethyl disulphide. The release of these gases causes the characteristic pulp mill odour. These compounds are odorous at concentrations of a few parts per billion (ppb), so a very small amount of any of the TRS compounds in the air can cause annoyance to the general public.

The TRS compounds originate from sodium sulphide, which is a necessary component of the cooking liquor (white liquor) used in the kraft pulping process. During the cook, wood chips are immersed in white liquor (a mixture of caustic soda and sodium sulphide) in a digester. The chips are cooked at a controlled temperature and pressure to break up and solubilize the lignin in the wood to free the cellulose fibres.

The spent cooking liquor (black liquor) is washed from the pulp in the brownstock washers and recovered. The liquor is concentrated in an evaporator and burned in the recovery boiler. The smelt in the bottom of the recovery boiler (residual inorganics from combustion) is removed and dissolved in water to form green liquor. The green liquor is contacted with lime to form white liquor which is re-used in the digesters.

3.1 TRS COMPOUNDS

3.1.1 Hydrogen Sulphide

Black liquor is a strongly alkaline solution which contains a high concentration of dissolved sodium sulphide. Black liquor has a normal pH of approximately 12. At a pH of 12, essentially all of the hydrogen sulphide forms hydrosulphide ions; therefore, there is very little dissolved hydrogen sulphide per se in the liquor. Some hydrogen sulphide (H_2S) gas can be released from the solution. Therefore, some H_2S can be released in the evaporator areas of the pulp mill or from any other area in which black liquor or recausticizing liquor contact a gas phase (i.e. brownstock washers).

In the recovery boiler, sulphur containing compounds from the black liquor are reduced, forming sodium sulphide. A small amount of hydrogen sulphide is also emitted. Similarly, in the lime kiln, residual sodium sulphide in the lime mud causes some TRS emissions. Incineration of

non-condensible gases or vent gases from a foul condensate stripper, in the lime kiln, can add to TRS emissions from the kiln.

3.1.2 Methyl Mercaptan

In the kraft process, the hydrosulphide ion reacts with the methoxy-lignin component of the wood during the cooking process to form methyl mercaptan. This is emitted as a component of the digester blow and relief gases which are generally vented and incinerated. Methyl mercaptan is present in low concentrations as a dissolved gas in black liquor but is emitted as the pH drops, such as occurs in the brownstock washers. Methyl mercaptan will dissociate in an aqueous solution to methyl mercaptide ions, and will dissociate almost completely at a pH above 12. The methyl mercaptide is then available to react with methoxy-lignin to produce dimethyl sulphide. Methyl mercaptan emissions increase when the pH of the liquor falls below 12.

Methyl mercaptan is only slightly soluble in water but is soluble in alcohol, ether and petroleum naphtha.

3.1.3 Dimethyl Sulphide

Dimethyl sulphide is present in black liquor and is highly volatile at normal liquor temperatures (150-200°F). It is formed through the reaction of methyl mercaptide ions with the methoxy-lignin component of wood. Dimethyl sulphide is insoluble in water, but soluble in alcohol and ether. It does not dissociate to form ionic species, so liquor pH has no impact on emissions of dimethyl sulphide.

3.1.4 Dimethyl Disulphide

Methyl mercaptan is oxidized to dimethyl disulphide throughout the recovery system. It has greater retention within the black liquor because it has a lower vapour pressure than the other TRS compounds. It does not dissociate to form ionic species, so pH has no impact on emissions.

3.2 EMISSION POINTS

TRS is generated in the recovery boiler and throughout the recovery process. There are many different points of emission of TRS compounds: i.e. wherever the spent pulping liquor contacts a gas stream. The main points of emission are the digester, multiple-effect evaporator system, recovery boiler, lime kiln, brownstock washer system and smelt dissolving tank. Table 3.1 gives typical uncontrolled emission rates for various kraft pulping processes.

The relative proportion of the individual TRS constituents differs for each process emission point (Table 3.2). TRS emissions are partly a function of liquor sulphidity.

Figure 3.1 illustrates the kraft pulping processes and emission points described below.

3.2.1 Digester System

A batch digester is charged with wood chips and cooking liquor (white and black liquor) and is capped. The digester contents are brought up to temperature either by a heat exchanger or by steam injection and they are "cooked" under pressure for a specified time (2-6 hours). After the "cook", the contents (pulp) are "blown" (released under pressure) into the blow tank. Continuous digesters are extremely large cooking vessels in which uninterrupted flows of wood chips and cooking liquor enter the top. Pulp is withdrawn continuously from the bottom into a blow tank, while spent cooking liquor is drawn off from the digester at mid-height and transferred to two flash tanks.

The sulphur content of the cooking liquor will greatly affect the TRS emissions from the digester. It is desirable to operate with the lowest practical sulphidity level in the white liquor. The desirable operating level for sulphidity is about 20% (Smook 1989) based on total titratable alkali. To adjust the sulphidity, the ratio of sulphur to sodium in the make-up chemicals must be altered.

The white sulphidity level required to minimize strength loss varies from mill to mill depending on the wood species pulped (softwood vs. hardwood) and product requirements. At a given mill, the sulphidity can vary somewhat from time to time as it can be difficult to control. Moreover, the optimal sulphidity for a given mill will be impacted by available sodium make-up sources.

Higher sulphidities reduce causticizing requirements. For many emission sources, the requirements for TRS control are not materially affected by the sulphidity level (Domtar 1994).

Digester blow and relief gases contain high concentrations of terpenes, organic compounds and organic sulphides. TRS concentrations in the non-condensibles can be as high as 30,000 ppm (U.S. EPA 1979) consisting primarily of dimethyl disulphide and dimethyl sulphide (Table 3.2). At nearly all kraft pulp mills, these emissions are collected and the turpentine is recovered by condensation. The remaining NCGs are combined with NCGs from the evaporator and subsequently burned in the lime kiln, power boiler, or a stand-alone incinerator.

Scrubbers are used to control the TRS in non-condensible gases at a few mills (U.S. EPA 1979) with white liquor as the scrubbing liquor. White liquor contains sodium hydroxide and is therefore effective at removing H_2S and methyl mercaptan, but it does not remove dimethyl sulphide or dimethyl disulphide. The TRS in non-condensible gases is normally 50-70% H_2S plus methyl mercaptan, so white liquor scrubbers are only 50-70% efficient at TRS removal.

The digester system produces foul condensate which is either steam stripped or sewered. If it is steam stripped, the condensate is reused as wash water in recausticizing or brownstock washing. The vent gas from the stripper must be incinerated in the lime kiln, power boiler or a stand-alone incinerator.

3.2.2 Brownstock Washer System

The contents of the blow tank are passed on to the brownstock washers. Sometimes, the pulp is defiberized, or deknotted, before brownstock washing. The pulp is passed through a series of washing drums counter-current to the washing liquid. TRS from this system consists primarily of methyl mercaptan, dimethyl sulphide and dimethyl disulphide (Table 3.2) which is released from the process liquid phase due to equilibrium driven mass transfer. In general, the washing liquid is process condensate from the evaporator system or, occasionally, fresh water. Use of process condensate will increase emissions of reduced sulphur compounds. The increase is dependent on the TRS content of the condensate.

For mill effluent closure, it is desirable to reuse low-contaminated process condensates in brownstock washing and recausticizing. However, the TRS content of these process condensates

Table 3.1

Kraft Pulping Uncontrolled TRS Emission Factors

Emission Point	Minimum Capacity (ADt/day)	Maximum Capacity (ADt/day)	Air Flow Rate (mm^3/Mg pulp/day)	Temp (°C)	Moisture Content (%)	TRS Emission Factor (kg/Mg AD pulp)		
						U.S.EPA 1993a	U.S.EPA 1979 *	
						Range	Range	Average
Vent Emission								
Digester Blow Gas								
Batch	94	1,800	1.3 [3]	82.5	30-99	2.37-4.02		
Continuous	94	1,800	0.026	112.5	35-70	2.4-4.0		
Digester Relief Gas	94	1,800	0.0026	42.5	3-20	2.6-2.7		
Digester System							0.24 - 5.3	0.75
Recovery Furnace							0.75 - 31	7.5
Black Liquor Oxidation Unit							0.005 - 0.37	0.05
Brown Stock Washer [1]	65	1,625	0.9	32.5	2-10	1.4-2.1		
Brown Stock Washer System [2]							0.005 - 0.5	0.15
BSW Seal and Foam Tank [3]	65	1,625	0.18	65	15-35	0.22		
Condensate Stripper System							-	1.0
Evaporator/hotwell [4]	65	1,625	0.0027	112.5	50-90	3.5		
Multiple Effect Evaporator System [4]							0.015 - 3.2	0.5
Lime Kiln							0.01 - 2.1	0.4
Smelt Dissolving Tank							0.007 - 1.9	0.1
Turpentine Condenser	94	1,800	0.00257	42.5	NA	2.7		
Tall Oil Reactor	65	1,625	0.000069-0.00763	40	NA	0.1		
Waste Water Emissions								
Digester Blow Condensates	94	1,800	0.69-1.4	40	NA	0.33		
Turpentine Decanter Underflow	94	1,800	0.11	40	NA	0.07		
Evaporator Condensates	65	1,625	4.2-4.9	40	NA	0.52		
Surface Condenser	65	1,625	4.2-4.9	40	NA	0.26		

* Based on 1000 ton per day Kraft Pulp Mill

Notes:

[1] likely washer hood vents

[2] not clear what this involves

[3] does not include washer hood vent gases

[4] evaporator/hotwell and multiple effect evaporator system are likely the same thing

[5] this is likely an instantaneous value - average value would be much less

TRS Emissions From Kraft Recovery Sources (AWMA 1992)

Source	TRS Emission Factor (kg H_2S/Mg ADTP)	
	Range	Average
Recovery Furnace DCE with BLO	0.005 - 0.09 [1]	na
Recovery Furnace NDCE	0.04 - 0.08	0.06
Smelt-dissolving Tank	0.005 - 0.03 [2]	na
Lime Kiln	0.005 - 0.06 [1]	na

Notes

[1] Based on TRS emissions guidelindes for existing kraft pulp mills

[2] Based on NSPS for SDTs of 0.016 g/kg BLS as H_2S

Note: the above factors appear to be too low by a factor of 5 to 10

TRS Emissions from Kraft Pulping (AWMA 1992)

Source	TRS Emission (kg H_2S/Mg ADTP)	
	Range	Average
Relief gases or turpentine condenser vent gases (batch)	0.006 - 0.76	0.27
Blow gases (batch)	0.17 - 0.55	0.37
Condenser vent gases, hardwood (continuous) [1]	0.11 - 0.48	0.27
Condenser vent gases, softwood (continuous)	na	na
Brown-stock washers [2]		
Fresh water	0.006 - 0.45	0.09 [3]
Condensate	0.07 - 0.49	0.25
Evaporator gases	0.02 - 3.39	0.62
Miscellaneous vent gases (batch) [5]	na	0.1
Condensate stripping system [4]	0.17 - 2.97	0.63

Notes:

[1] estimates are for continuous digesters without diffusion washers only

[2] includes gases to roof vents and from undervents (vacuum pump exhausts and filtrate seal tanks)

[3] estimates for fresh water use only; includes washer seal tanks and pulp knotter vents

[4] untreated stripped gas

[5] TRS emissions from vacuum-drum-type washing systems; TRS for newer diffusion washers are <0.001 lb/ADTP

TABLE 3.2
Pulp Mill Emission Factors (Uncontrolled) for Individual Sources and Compounds (U.S. EPA 1993a)

Wood Type	Mill Process	Emission Point	Emissions (kg/Mg air dry pulp)						
			Hydrogen Sulphide	Methyl Mercaptan	Dimethyl Sulphide	Dimethyl Disulphide	Dimethyl Trisulphide	Carbon Disulphide	Total TRS
H	Digesters	Batch relief gases	0.027	0.225	0.823	1.542	0	0	2.617
H	Digesters	Continuous relief gases	0.069	0.245	0.823	1.542	0	0	2.679
S	NCG system	Batch turpentine condenser	0.069	0.245	0.823	1.542	0	0	2.679
S	NCG system	Continuous turpentine condenser	0.069	0.245	0.823	1.542	0	0	2.679
S	Tall Oil Recovery	Batch vent	0.0957	0.0033	0.0022	0.00033	0	0	0.10153
S	Tall Oil Recovery	Continuous vent	0.0957	0.0033	0.0022	0.00033	0	0	0.10153
S	NCG System	Turpentine condensates	0.0067	0.0161	0.0265	0.0218	0	0	0.0711
S	NCG System	Turpentine condensates (IMP)	0.0067	0.0161	0.0265	0.0218	0	0	0.0711
H	Digesters	Batch blow condensates	0.098	0.113	0.101	0.0183	0	0	0.3303
S	Digesters	Batch blow condensates	0	0.113	0.101	0.0183	0	0	0.2323
H	Digesters	Batch blow gases	0.053	0.075	2.422	1.469	0	0	4.019
S	Digesters	Batch blow gases	0.053	0.075	2.422	1.469	0	0	4.019
H	Digesters	Continuous blow gases ND	0.053	1.125	0.533	0.661	0	0	2.372
S	Digesters	Continuous blow gases ND	0.053	1.125	0.533	0.661	0	0	2.372
H	Digesters	Continuous blow condensates I	0.098	0.113	0.101	0.0183	0	0	0.3303
S	Digesters	Continuous blow condensates I	0.098	0.113	0.101	0.0183	0	0	0.3303
H	Washers	Hood vent	0.053	0.788	0.533	0.01	0.071	0.001	1.456
S	Washers	Hood vent	0.053	0.788	0.533	0.661	0.071	0	2.106
S	Washers	Foam tank	0	0.045	0.116	0.059	0	0	0.22
H	Washers	Foam tank	0	0.0453	0.116	0.059	0	0	0.2203
H	Evaporators	Vent	0.823	0.638	0.533	1.542	0	0	3.536
S	Evaporators	Vent	0.823	0.638	0.533	1.542	0	0	3.536
H	Evaporators	Condensates	0.364	0.126	0.0224	0.0123	0	0	0.5247
S	Evaporators	Condensates	0.364	0.126	0.0224	0.0123	0	0	0.5247
H	Evaporators	Surface cond. condensates	0.195	0.0421	0.0215	0.00546	0	0	0.26406
S	Evaporators	Surface cond. condensates	0.195	0.0421	0.0215	0.00546	0	0	0.26406

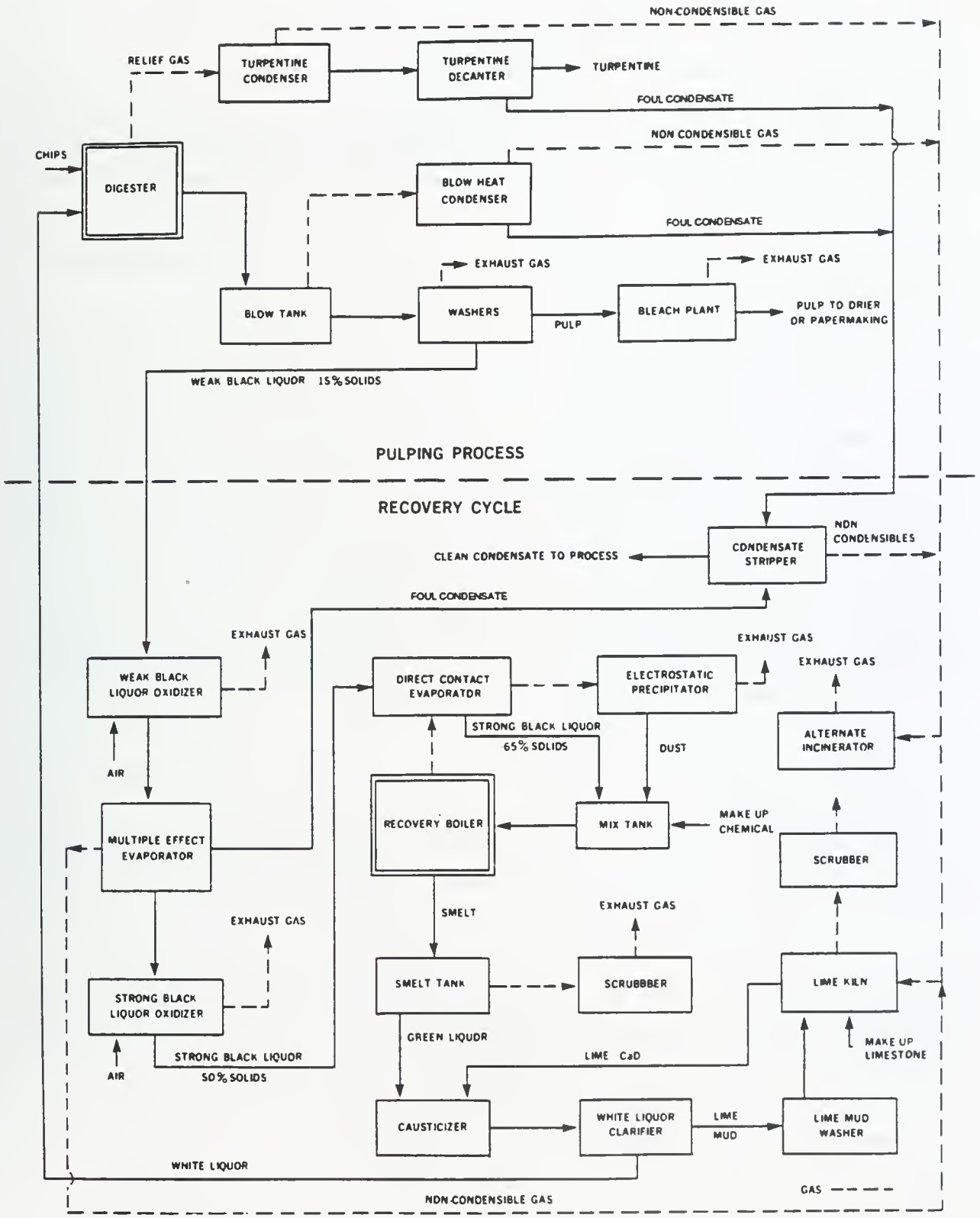
Notes: H - hardwood
S - softwood

Typical Reduced Sulfur Gas Emissions (Springer 1986)

Emission Point	Emissions (kg S /tonne air-dried pulp)			
	Hydrogen Sulphide	Methyl Mercaptan	Dimethyl Sulphide	Dimethyl Disulphide
Digester, batch				
Blow gases	0 - 0.15	0 - 1.3	0.05 - 3.3	0.05 - 2.0
Relief gases	0 - 0.05	0 - 0.3	0.05 - 0.8	0.05 - 1.0
Digester, continuous	0 - 0.1	0.5 - 1.0	0.05 - 0.5	0.05 - 0.4
Washer hood vent	0 - 0.01	0.05 - 1.0	0.05 - 0.5	0.05 - 0.4
Washer seal tank	0 - 0.01	0 - 0.01	0 - 0.05	0 - 0.03
Evaporator hotwell	0.05 - 1.5	0.05 - 0.8	0.05 - 1.0	0.05 - 1.0
Black Liquor Oxidation tower exhaust	0 - 0.01	0 - 0.1	0 - 0.4	0 - 0.3
Recovery furnace (1)	0 - 25	0 - 2	0 - 1	0 - 0.3
Recovery furnace (2)	0 - 1	0 - 0.01	0 - 0.01	0 - 0.01
Smelt-dissolving tank	0 - 1	0 - 0.8	0 - 0.05	0 - 0.3
Lime kiln exhaust	0 - 0.5	0 - 0.2	0 - 0.1	0 - 0.05
Lime slaker vent	0 - 0.01	0 - 0.01	0 - 0.01	0 - 0.01

Notes: (1) after direct contact evaporation
(2) without direct contact evaporation

Figure 3.1
KRAFT PULPING PROCESS



Adapted from Environment Canada 1979

should be minimized, because some of the TRS in the recycled condensates will escape as air emissions. To minimize the TRS emissions, it is important to properly segregate the process condensates. Streams with higher TRS contamination should be sent to a foul condensate stripper (steam stripping) and the stripper should be operated to remove 95-98% of the TRS. This may require acidification of the stripper feed. Steam stripping of process condensates prior to reuse in brownstock washing and recausticizing also minimizes VOC emissions from these sources.

Two types of brownstock washers are available: displacement and diffusion washers. Vacuum washers are the most common type of displacement washers.

Emissions from vacuum washers are released from the hood vent and seal tank vents. Emissions can be collected from the vents, although a considerable volume of air is collected at the same time because the system is not fully enclosed. Historically, these gases have been vented directly to the atmosphere. One way of treating these high volume and relatively low concentration gases is to use them as part of the combustion air in the recovery boiler or power boiler (see Table 3.3). It should be possible to implement this feature on any recovery boiler. The age of the boiler and its original design are not issues. Typically, the brownstock washer gases are collected and directed to the suction side of the recovery boiler forced draft fan. This can be done by providing an enclosure around the forced draft fan. Brownstock washer gases can also be burned in a dedicated incinerator or scrubbed with a caustic solution.

It is advantageous to avoid a high moisture content in the combustion air on recovery boilers. High moisture increases the flue-gas flow, which reduces the furnace capacity. The thermal recovery efficiency is also reduced. A high moisture content in the combustion air, especially entrained liquid water, can create a potentially explosive condition at the smelt bed, particularly if the air is not injected in the upper zones of the recovery boiler.

Some washer hoods can be entirely enclosed and pressurized. This fairly new development, referred to as pressure washers, substantially reduces the volume of air to be treated but increases the concentration of the emissions. Recent experience with pressure washers (Domtar 1995) has found the pressure washer design to not be reliable. TRS emissions at the pressure washers are low but are released from vent tanks and at the paper machines.

Diffusion washing takes place in a fully enclosed vessel and involves very little air, with the pulp mass being essentially submerged. Therefore, emissions are almost eliminated (two orders of magnitude less than vacuum washers or 0.001 lb. TRS/ton ADP compared to 0.1 lb. TRS/ton ADP) (Springer 1986). Ideally, use of the diffusion washers could almost eliminate emissions from this source. However, switching from vacuum to diffusion washers would involve considerable capital expense.

3.2.3 Pulp Bleaching

Nearly 60% of all chemical pulps are bleached to impart whiteness or brightness to the pulp, in addition to yielding certain desirable physical and chemical properties (AWMA 1992). Kraft pulps usually undergo multi-stage lignin-removal processes. There have been significant changes in the bleaching process and compounds used in recent years because of environmental concerns with certain bleaching by-products formed when using chlorine as the main bleaching agent. The by-products formed include certain dioxins and furans, as well as chloroform. The substitution of chlorine dioxide for chlorine and the elimination or reduction of sodium hypochlorite virtually eliminates the emissions of these hazardous by-products. Fugitive TRS may also be emitted from the bleach plant because of residual black liquor in the pulp. TRS emission rates (if TRS compounds are present) are generally low because the process conditions are highly oxidizing. Accordingly, TRS emissions are often not often controlled. When bleach plant gases are scrubbed with caustic to remove chlorine dioxide and chlorine, some of the TRS is removed as well.

3.2.4 Black Liquor Oxidation

Black liquor oxidation was developed to reduce odour from direct-contact evaporators which are part of older recovery boiler designs. Black liquor is contacted with air or molecular oxygen to oxidize sulphide to thiosulphate which stabilizes the sulphur compounds in the black liquor, thereby reducing TRS emissions. If molecular oxygen is used, the system is closed and there are no vent gases. As the oxidation step may cause foam generation, a foam tank may be necessary.

The black liquor can be oxidized at different stages of the recovery process; either before black liquor evaporation (weak liquor oxidation), after black liquor evaporation (strong liquor oxidation), or a combination of the two. Weak liquor is easier to oxidize and results in an

Table 3.3

RACT/BACT/LAER Summaries - Pulp and Paper TRS/H_2S Emissions

FACILITY	PROCESS	THROUGH-PUT	THROUGHPUT UNIT	POLLUTANT	EMISSION RATE	EMISSION UNIT	CONTROL EQUIPMENT	PROCESS MODIFICATION	CATEGORY
S D. WARREN CO.	BOILER	395.00	MMBTU/H	TRS	5.0000	PPMV		MIN FIREBOX TEMP & RESID. TIME, 1200 F & 0.5 SEC	NSPS
WEYERHAEUSER CO.	BOILER, POWER	1400.00	MMBTU/H	TRS	0.0036	LB/MMBTU	INCINERATION		BACT-PSD
LEAF RIVER FOREST PRODUCTS	BOILER, RECOVERY	6.40	MM LB/DAY BLS	TRS	5.0000	PPM @ 8% O2	COMBUSTION CONTROL	OPTIMIZATION OP COMBUSTION PROCESS	BACT-PSD
UNION CAMP CORP.	BOILER, KRAFT RECOVERY	2.60	MM LB/D BLS	TRS	5.0000	PPMV DRY T		AT 8% O2	BACT-PSD
UNION CAMP CORP.	BOILER, KRAFT RECOVERY	2.30	MM LB/D BLS	TRS	5.0000	PPMV DRY T		AT 8% O2	BACT-PSD
UNION CAMP CORP.	BOILER, KRAFT RECOVERY	2.90	MM LB/D BLS	TRS	5.0000	PPMV DRY T		AT 8% O2	BACT-PSD
HAMMERMILL PAPER	BOILER, RECOVERY, #2	737.00	MMBTU/H	TRS	5.0000	PPM AT 8% O2		BOILER DESIGN & OPERATION	NSPS
KIRBY FOREST INDUSTRIES	BOILER, RECOVERY	935.00	MMBTU/H	TRS	6.1000	LB/H	CAUSTIC SCRUB. SYS.		NSPS
SIMPSON LEE PAPER CO.	BOILER, RECOVERY	6000.00	GAL/H B.L.	TRS	0.0000				NSPS
WEYERHAEUSER CO.	SMELT TANK	75.00	T/H OF MOLTEN SALT	TRS	0.0168	LB/T BLS		EQUIPMENT OPERATION	NSPS
KIRBY FOREST INDUSTRIES	SMELT TANK	3446806.00	LB/D	TRS	1.2000	LB/N			BACT-PSD
LEAP RIVER FOREST	BOILER, RECOVERY	0.00		TRS	5.0000	PPM AT 8% FUEL		BOILER OPERATION	BACT-PSD
INDEPENDENT KRAFT CORP.	STRIPPER, CONDENSATE	763.00	T ADP/D	TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
LEAP RIVER FOREST	SMELT DISSOLVING TANK	0.00		TRS	0.1680	LB/T BLS		EQUIPMENT OPERATION	NSPS
ALABAMA RIVER PULP CO., INC	BOILER, RECOVERY	1086.00	T ADP/D	TRS	5.0000	PPM AT 8% O2		LOW ODOR BOILER	BACT-PSD
SCOTT PAPER	BOILER, RECOVERY	1100.00	T/D ADP	TRS	5.0000	PPM		EQUIPMENT OPERATION & CONTROL	NSPS
INDEPENDENT KRAFT CORP.	BROWN STOCK WASHER	763.00	T ADP/D	TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
SCOTT PAPER	EVAPORATOR	0.00		TRS	0.5000	SEC AT 1200 F		INCINERATION	BACT-PSD
ALABAMA RIVER PULP CO., INC	DIGESTER	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION-LIME KILN		BACT-PSD
INDEPENDENT KRAFT CORP.	SMELT TANK	763.00	T ADP/D	TRS	0.0168	LB/T BLS			BACT-PSD
HAMMERMILL PAPER	SMELT DISSOLVING TANK	56.25	T/H BLS	TRS	0.0168	LB/T BLS		RECOVERY BOILER OPERATION	NSPS
HAMMERMILL PAPER	DIGESTER, BATCH, #6-8	0.00		TRS	0.5000	SEC AT 1200 F		INCINERATION	BACT-PSD
ALABAMA RIVER PULP CO., INC	EVAPORATOR	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION-LIME KILN		BACT-PSD
HAMMERMILL PAPER	BOILER, RECOVERY, #1	382.00	MMBTU/H	TRS	20.0000	PPM			BACT-PSD
ALABAMA RIVER PULP CO., INC	BROWN STOCK WASHER	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION-RECOV. BOILER		BACT-PSD
WEYERHAEUSER CO.	BOILER, RECOVERY, KRAFT MILL	155.00	T/H BLS	TRS	5.0000	PPM		EQUIPMENT OPERATION	NSPS
UNION CAMP CORP.	BOILER, RECOVERY, #2	1340.00	T ADP/D	TRS	5.0000	PPM AT 8% O2		LOW ODOR BOILER	BACT-PSD
UNION CAMP CORP.	BROWN STOCK WASHER	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
UNION CAMP CORP.	EVAPORATOR	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
UNION CAMP CORP.	DIGESTER	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
INDEPENDENT KRAFT CORP.	BOILER, RECOVERY	763.00	T ADP/D	TRS	0.5000	PPM AT 8% O2		LOW ODOR BOILER	BACT-PSD
UNION CAMP CORP.	NO. 2 SMELT DISSOLVING TANKS	1344.00	T ADP/D	TRS	0.0168	LB/T BLS			BACT-PSD
INDEPENDENT KRAFT CORP.	DIGESTER, CONTINUOUS	763.00	T ADP/D	TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
HAMMERMILL PAPER	BROWN STACK WASHER #2	0.00		TRS	11.0000	LB/H			BACT-PSD
SCOTT PAPER	SMELT TANK	45.80	T/H	TRS	0.0168	LB/T BLS		EQUIPMENT DESIGN	NSPS
INDEPENDENT KRAFT CORP.	EVAPORATOR, MULTIPLE EFFECTS	763.00	T ADP/D	TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
CHAMPION INTERNATIONAL CORP.	BOILER, RECOVERY	380000.00	LB/H	TRS	5.0000	PPM BY VOL			BACT-PSD
CHAMPION INTERNATIONAL CORP.	SMELT DESOLVING TANK	2.86	MMLB/D BLS	TRS	0.0108	LB/T	SCRUBBER		NSPS
WESTVACO CORP.	BOILER, RECOVERY, #10	187500.00	LB/H BLS	TRS	0.0168	LB/T BLS		EQUIPMENT OPERATION	NSPS
BOWATER CAROLINA CO.	FURNACE, RECOVERY	900.00	T/D ADP	TRS	5.0000	PPM		BL. LIQUOR NON-CONTACT EVAPOR.	BACT-PSD
BOWATER CAROLINA CO	SMELT DISSOLVING TANK	30.00	T/H OF SMELT	TRS	0.0168	LB/T BLS	WET SPRAY SCRUB. W/CYC. FLOW		BACT-PSD
WILLAMETTE INDUSTRIES, INC.	FURNACE, RECOVERY	600.00	T/D ADP	TRS	5.0000	PPMV DRY BASIS AT 8%		LOW ODOR FURNACE	BACT-PSD
WILLAMETTE INDUSTRIES, INC.	SMELT DISSOLVING TANK	600.00	T/D ADP	TRS	0.0168	LB/T BLS			NSPS
WILLAMETTE INDUSTRIES, INC.	MULTIPLE EFFECT EVAP. LINE	600.00	T/D ADP	TRS	0.0000		INCINERATION IN LIME KILN		NSPS
NEKOOSA PAPER CO.	BOILER, RECOVERY	4.40	MMLB/D BLS	TRS	5.0000	PPM			NSPS
NEKOOSA PAPER CO.	SMELT TANK	57000.00	LB/H SALT	TRS	0.0084	G/KG			NSPS
GEORGIA-PACIFIC CORP.	BOILER, RECOVERY, NO. 5	607500.00	LB/H STEAM AT 900P	TRS	5.0000	PPMV DRY CORR TO 8%			NSPS
GEORGIA-PACIFIC CORP.	SMELT TANK, NO. 5, 2 TOTAL	63000.00	LB/H SMELT	TRS	0.0168	LB/T LIQUOR SOLIDS.			NSPS
LOUISIANA PACIFIC CORP.	BOILER, RECOVERY	830.00	T/D ADP	TRS	3.0000	PPM		LOW ODOR DESIGN	BACT-PSD
LOUISIANA PACIFIC CORP.	TANK, SMELT DISSOLVING	830.00	T/D ADP	TRS	0.0168	LB/T BLS	WET SCRUBBER		BACT-PSD
MEAD COATED BOARD	DIGES./EVAPS./BSW	0.00		TRS	0.0000		INCINERATION		BACT-PSD
MEAD COATED BOARD	TANK, SMELT, NO. 2	93.80	T/H BLS	TRS	0.0330	LB/T BLS			BACT-PSD
MEAD COATED BOARD	BOILER, RECOVERY, #2	1500.00	T ADP/D	TRS	5.0000	PPMV AT 8% O2			BACT-PSD
BOISE CASCADE	WASHER, BROWN STOCK	1000.00	BDTUP/D	TRS	0.1200	LB/T ADUP			BACT-PSD
BOISE CASCADE	BOILER, RECOVERY	571.00	MMBTU/H	TRS	5.0000	PPMDV AT 8% O2		COMBUSTION CONTROL	BACT-PSD
BOISE CASCADE	SMELT TANK	2.30	MMLB/D BLS	TRS	0.0330	LB/T BLS	EXISTING SCRUBBER		BACT-PSD
BOISE CASCADE	STRIPPER/HEAT RECOV./COND./EVAP.	0.00		TRS	0.0000		INCINERATE L.K. W/SO2 SCRUBBER		BACT-PSD
GEORGIA-PACIFIC CORP.	BOILER, RECOVERY	1430.00	T/D ADP	TRS	5.0000	PPM, 12H AVG		COMBUSTION CONTROL	BACT-PSD
JAMES RIVER CORP.	SCRUBBER, SMELT TANK	0.00		TRS	0.0168	LB/T BLS	PUCON FAN/PACKED BED SCRUBBER		BACT-PSD
S D. WARREN CO.	BOILER, RECOVERY	375.00	MMBTU/H	TRS	5.0000	PPM, 12H AVG		COMBUSTION CONTROL	BACT-PSD
BOISE CASCADE CORP.	BOILER, RECOVERY	4.00	MMLB/D BLS	TRS	5.0000	PPM, 12H AVG		COMBUSTION CONTROL	BACT-PSD
ALABAMA RIVER PULP CO.	DIGES.,EVAPS.,STRIPPER,BSW, #2	0.00		TRS	0.0000		INCINERATION		BACT-PSD
ALABAMA RIVER PULP CO.	BOILER, RECOVERY, #2	5.50	MMLB/DAY BLS	TRS	5.0000	PPMV AT 8% O2			BACT-PSD
ALABAMA RIVER PULP CO.	TANK, SMELT, #2	114.60	T/H BLS	TRS	0.0330	LB/T BLS			BACT-PSD
WEYERHAEUSER CO.	BOILER, RECOVERY	5.00	MMLB/D BLS	TRS	5.0000	PPMVD AT 8% O2			BACT-PSD
WEYERHAEUSER CO.	TANK, SMELT DISSOLVING	5.00	MMLB/D BLS	TRS	0.0330	LB/SHORT T BLS	WET SCRUBBER W/LOW SULFIDE LIQ		BACT-PSD
INTERNATIONAL PAPER COMPANY	BOILER, RECOVERY	1117.00	T ADP	TRS	5.1000	LB/H, NOTE 2	NONCONTACT EVAPORATOR		BACT-PSD
INTERNATIONAL PAPER COMPANY	SMELT TANK	0.00		TRS	2.3000	LB/H, NOTE 8	WET SCRUBBER		BACT-PSD

Table 3.3

RACT/BACT/LAER Summaries - Pulp and Paper TRS/H_2S Emissions

FACILITY	PROCESS	THROUGH-PUT	THROUGHPUT UNIT	POLLUTANT	EMISSION RATE	EMISSION UNIT	CONTROL EQUIPMENT	PROCESS MODIFICATION	CATEGORY
LEAF RIVER FOREST PRODUCTS	TANK, SMELT	6.00	MMLB/D BLS	TRS	0.0330	LB/T BLS, DRY	ESP		BACT-PSD
PENNTECH PAPERS INC.	KRAFT RECOVERY FURNACE	630.00	ADT/DAY	TRS	5.0000	PPM(V) DRY AT 8% O2	NONE		NSPS
PENNTECH PAPERS INC.	SMELT DISSOLVING TANK	630.00	ADT/DAY	TRS	18.5000	PPM(V) DRY AT 10% O2	NONE		NSPS
GREAT SOUTHERN PAPER	BOILER, RECOVERY, #1	63.56	T/H BLS	TRS	4.7400	LB/H			NSPS
GREAT SOUTHERN PAPER	TANK, SMELT, #1	63.56	T/H BLS	TRS	1.0500	LB/H			NSPS
GREAT SOUTHERN PAPER	BOILER, RECOVERY, #2	63.56	T/H BLS	TRS	4.7400	LB/H			NSPS
GREAT SOUTHERN PAPER	TANK, SMELT, #2	63.56	T/H BLS	TRS	1.0500	LB/H			NSPS
WILLAMETTE INDUSTRIES	KILN #1, LIME	220.00	T/D CAO	TRS	8.0000	PPM AT 10% O2		PROCESS CONTROLS	NSPS
WILLAMETTE INDUSTRIES	EVAPORATOR, MULTIPLE EFFECT	840.00	T/D ADP	TRS	5.0000	PPM, DRY BASIS	VENTED TO NCG INCINERATOR OR L. K.		BACT-PSD
WILLAMETTE INDUSTRIES	BOILER, RECOVERY, #1	840.00	T/D ADP	TRS	5.0000	PPM AT 8% O2		LOW ODOR DESIGN BOILER	NSPS
WILLAMETTE INDUSTRIES	WASHER, BROWN STOCK	840.00	T/D ADP	TRS	5.0000	PPM, DRY BASIS	VENTED TO NCG INCINERATOR OR L. K.		BACT-PSD
WILLAMETTE INDUSTRIES	DISSOLVING TANK #1, SMELT	840.00	T/D ADP	TRS	0.0300	LB/T BLS		NON-SULFIDE SCRUBBING LIQUID	BACT-PSD
WILLAMETTE INDUSTRIES	TANK, ACCUMULATOR	840.00	T/D ADP	TRS	5.0000	PPM, DRY BASIS	VENTED TO NCG INCINERATOR OR L. K.		BACT-PSD
UNION CAMP PULP AND PAPER MILL	FURNACE, RECOVERY #1	822.00	T/D ADP	TRS	8.0000	PPM AT 8% O2		LOW ODOR DESIGN BOILER	NSPS
UNION CAMP PULP AND PAPER MILL	WASHING SYSTEM #2, BROWN STOCK	1463.00	T/D ADP	TRS	0.0000	COMPLETE COMBUSTION	INCINERATION		NSPS
UNION CAMP PULP AND PAPER MILL	STRIPPING SYSTEM #2, CONDENSATE	1463.00	T/D ADP	TRS	0.0000	COMPLETE COMBUSTION		VENTED TO INCINERATOR #2/BOILER #2	BACT-PSD
UNION CAMP PULP AND PAPER MILL	TANK, SMELT DISSOLVING, #2	1463.00	T/D ADP	TRS	0.0168	LB/T BLS		NON-SULFIDE SCRUBBING LIQUID	BACT-OTHER
UNION CAMP PULP AND PAPER MILL	TANK, SMELT DISSOLVING, #1	822.00	T/D ADP	TRS	0.0168	LB/T BLS		NON-SULFIDE SCRUBBING LIQUID	LAER
UNION CAMP PULP AND PAPER MILL	EVAPORATOR SET #2	1463.00	T/D ADP	TRS	0.0000	COMPLETE COMBUSTION		VENTED TO INCINERATOR #2/BOILER #2	BACT-PSD
UNION CAMP PULP AND PAPER MILL	DIGESTER SYSTEM #2	1463.00	T/D ADP	TRS	0.0000	COMPLETE COMBUSTION	INCINERATION		NSPS
UNION CAMP PULP AND PAPER MILL	BOILER, RECOVERY, #2	1463.00	T/D ADP	TRS	5.0000	PPM AT 8% O2		LOW ODOR DESIGN BOILER	NSPS
GULF STATES PAPER	SMELT TANK NO. 3	3.30	MMLB/D BLS	TRS	0.0330	LB/T BLS			BACT-PSD
CHESAPEAKE CORP.	TANK, SMELT DISSOLVING, #5	0.00		TRS	0.0168	LB/T BLS AS H2S	SCRUBBER, LOW SULFIDES H2O		BACT-PSD
CHESAPEAKE CORP.	BOILER, CHEMICAL RECOVERY	62.50	T BLS/H	TRS	5.0000	PPMDV AT 8%O2	LOW ODOR DESIGN RECOVERY BOILER		BACT-PSD
GULF STATES PAPER	DIGESTER AND EVAPORATORS	0.00		TRS	0.0000			INCINERATION	BACT-PSD
RIVERWOOD INTERNATIONAL	BOILER, RECOVERY	3.50	MMLB/D BLS	TRS	5.0000	PPM		DESIGN	NSPS
RIVERWOOD INTERNATIONAL	TANK, SMELT	3.50	MMLB/D	TRS	0.0168	LB/T BLS			OTHER
MACMILLAN BLOEDAL	WASHER	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
MACMILLAN BLOEDAL	SMELT TANK	87.00	T/H BLS	TRS	0.0168	LB/T BLS		EQUIPMENT OPERATION	NSPS
MACMILLAN BLOEDAL	BOILER, RECOVERY	960.00	MMBTU/H	TRS	5.0000	PPM AT 8% O2		EQUIPMENT OPERATION	NSPS
MACMILLAN BLOEDAL	DIGESTER	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
MACMILLAN BLOEDAL	EVAPORATOR	0.00		TRS	0.5000	SEC AT 1200 F	INCINERATION		BACT-PSD
STONE CONTAINER CORP.	BOILER, CROSS RECOVERY	800.00	TADP/D	TRS	25.0000	PPM		DESIGN/COMBUSTION CONTROL	OTHER
STONE CONTAINER CORP.	SMELT TANK	0.00		TRS	0.0330	LB/T LIQUOR SOLIDS,	WET SCRUBBER		BACT-PSD
UNION CAMP CORP.	KILN, LIME	205.00	T/D (SEE NOTE)	TRS	10.0000	LB/T ADP			BACT-PSD
UNION CAMP CORP.	KILN, LIME	255.00	T/D (SEE NOTE)	TRS	10.0000	LB/T ADP			BACT-PSD
UNION CAMP CORP.	KILN, LIME	230.00	T/D (SEE NOTE)	TRS	10.0000	LB/T ADP			BACT-PSD
WEYERHAEUSER CO.	KILN, LIME	21.00	T/H	TRS	8.0000	PPM		EQUIPMENT OPERATION	NSPS
LEAF RIVER FOREST	KILN, LIME	0.00		TRS	8.0000	PPM		EQUIPMENT OPERATION	NSPS
INDEPENDENT KRAFT CORP.	KILN, LIME	763.00	T ADP/D	TRS	8.0000	PPM AT 10% O2			BACT-PSD
UNION CAMP CORP.	KILN, LIME, #2	1460.00	T ADP/D	TRS	8.0000	PPM AT 10% O2			BACT-PSD
HAMMERMILL PAPER	KILN, LIME	0.00		TRS	8.0000	PPM AT 10% O2		EQUIPMENT OPERATION	NSPS
ALABAMA RIVER PULP CO., INC	KILN, LIME	1086.00	T ADP/D	TRS	5.0000	PPM AT 10% O2			BACT-PSD
KIRBY FOREST INDUSTRIES	KILN, LIME	275.00	T/D CAO	TRS	3.5000	LB/H			NSPS
CHAMPION INTERNATIONAL CORP.	KILN, LIME	280.00	T/D CAO	TRS	8.0000	PPM BY VOL	SCRUBBER		NSPS
GEORGIA-PACIFIC CORP.	KILN, LIME, NO. 3	63299.00	LB/H LIME MUD	TRS	8.0000	PPMV DRY CORR TO 10%			NSPS
BRUNSWICK PULP & PAPER CO.	KILN, LIME, #5	1060.00	T/D LIME MUD SOLIDS	TRS	8.0000	PPM AT 10% O2	AHLSTROM EDUCTION SCRUBBER		NSPS
HAMMERMILL PAPER	KILN, LIME, #3	380.00	T/D	TRS	8.0000	PPM AT 10% O2		DESIGN	NSPS
MEAD COATED BOARD	KILN, LIME, NO 2	1200.00	T ADP/D	TRS	8.0000	PPMV AT 10% O2			BACT-PSD
BOISE CASCADE	KILN, LIME	230.00	T/D	TRS	8.0000	PPMDV AT 10% O2, 12H		COMBUSTION CONTROL	BACT-PSD
NEKOOSA PAPERS, INC.	KILN, LIME, #3	440.00	T/D LIME	TRS	8.0000	PPMV, DRY BASIS, COR		PROPER KILN OPERATION	OTHER
BOISE CASCADE CORP.	KILN, LIME	327.00	T/D PRODUCT	TRS	8.0000	PPM, 12H AVG			BACT-PSD
ALABAMA RIVER PULP CO	KILN, LIME, #2	465.00	T/D CAO	TRS	8.0000	PPMV AT 10% O2			BACT-PSD
WEYERHAEUSER CO.	KILN, LIME	21.00	T/H	TRS	8.0000	PPMVD AT 10% O2	INCINERATION		BACT-PSD
UNION CAMP PULP AND PAPER MILL	KILN, LIME, #2	265.00	T/D CAO	TRS	8.0000	PPM AT 10% O2		PROCESS CONTROLS	NSPS

increase in the yield of tall oil, reduced corrosion and scaling of evaporator tubes and improved condensate quality. TRS emissions in the evaporator non-condensible gases are also reduced. However, there are many problems associated with this process, so it is not generally used. Strong liquor oxidation is widely practiced. Because the liquor is concentrated, there is less volume to handle. Oxidation efficiencies of 97 to 98% can be achieved at a 30 g/L Na_2S inlet concentration and a 2.5 hour retention time using a one-stage system (Springer 1986). Two-stage systems offering higher removal efficiencies (up to 99.95%) have been reported.

Disadvantages of black liquor oxidation (Springer 1986) include:

1) A reduction of 2 to 6% in black liquor heating value may occur;
2) Organic sulphides are not oxidized and therefore remain volatile and odorous;
3) Incomplete oxidation and reversion are possible;
4) Elemental sulphur or polysulphides may form, which may revert to the undesirable hydrosulphide ion (odorous) in a later process; and
5) The effluent gas from the oxidation process may be contaminated with volatile sulphur compounds. Ideally, this gas stream should be collected and burned in an on-site incineration device (e.g. power boiler or dedicated incinerator).

Emissions from black liquor oxidation systems are generally vented to the atmosphere (U.S. EPA 1979) but could be incinerated in a power boiler or dedicated incinerator. If the moisture content of the gas were significantly reduced, the gas might be incinerated in a recovery boiler. Some VOCs are stripped from the black liquor during black liquor oxidation and will be released in the vent gases. These emissions are high volume, low TRS content and the moisture content of the vent gases must be reduced for incineration, especially for use in a recovery boiler.

3.2.5 Multiple-Effect Evaporator System

Weak black liquor (15% solids) from the brownstock washers is collected and concentrated to approximately 50% (strong black liquor) in the multiple-effect evaporators. These are a series of evaporators operating at different (increasing) pressures. As the black liquor passes from stage to stage, it becomes increasingly concentrated and therefore decreases in volume, and the pressure and the boiling temperature increase.

Vapour from the last stage and vent gases from preceding stages are fed to one or more surface condensers. The condensate lines from these condensers go down to a seal tank which is referred to as a hotwell. The non-condensible gas vent line from the final condenser usually goes to the hotwell. Another vent line goes from the seal tank to the gas withdrawal system (steam jet ejector or water ring vacuum pump) which removes the non-condensible gases to allow the condensers to create the vacuum. The condensate from the hotwell contains some TRS compounds.

The concentration of TRS in the non-condensible gases can be as high as 44,000 ppm (U.S. EPA 1979). Usually, the non-condensible gases are fed into an incineration device. The devices used for incineration include the lime kiln, power boiler or a stand-alone incinerator. A recovery boiler has been used in a few cases. A stand-alone incinerator could be used as a backup control system if process equipment such as a lime kiln is not operating continuously, but this is an expensive solution. The most common destruction facility for non-condensible gases is the lime kiln.

In some mills, NCGs are scrubbed with white liquor, which can remove the H_2S and methyl mercaptan but not the dimethyl sulphide or dimethyl disulphide. The overall removal efficiency for TRS is usually about 50-65%, which is the H_2S and methyl mercaptan component. White liquor scrubbing of NCGs can be used as a complementary measure to incineration, to reduce SO_2 emissions from incineration. A white liquor scrubber can also be used as a back-up for incineration. White liquor scrubbing is not considered a primary control technique.

Multiple effect evaporators produce foul condensate (heavily contaminated), as well as contaminated condensate (lightly contaminated). Contaminated condensate is reused directly as wash water in brownstock washing and/or recausticizing. Foul condensate is either stripped before use or sewered.

3.2.6 Tall Oil Plant

During the black liquor concentration cycle, the black liquor may be skimmed at a concentration of 24% to 28% solids to remove "soap". The soap is reacted with sulphuric acid to convert the soap to a tall oil (which is a saleable product) and recover the sodium sulphate. The reaction is the following:

$$Na \cdot R + H_2SO_4 \rightarrow H \cdot R + Na_2SO_4$$

TRS is released during this process. These TRS emissions can be controlled with a scrubber using caustic or white liquor.

3.2.7 Recovery Boiler

TRS concentrations in recovery boiler flue-gas can range from as low as 1 ppm to several hundred ppm (U.S. EPA 1979) depending on the boiler design and operation. Variables which can effect TRS generation are:

- relative quantity and distribution of combustion air;
- rate of solids (concentrated black liquor) feed;
- spray pattern and droplet size of the liquor feed;
- gas turbulence in the oxidation zone;
- intermittent gas smelt bed disturbance caused by dried liquor falling off the furnace walls; and
- the combination of sulphidity and heat content value of the liquor feed.

These variables can affect the TRS generation regardless of whether the evaporator is direct- or indirect-contact.

A direct-contact evaporator (used to raise the solids content to approximately 65 to 70% to form heavy black liquor) generates increased quantities of TRS, depending on the concentration of sodium sulphide in the black liquor. Contact with acidic gases such as CO_2 can release hydrogen sulphide and methyl mercaptan. About half of the recovery boilers in Canada have indirect-contact evaporators, so that the black liquor does not come into contact with combustion gases. This is known as a low odour recovery boiler. Older recovery boilers with direct-contact

evaporators should have a black liquor oxidation system to control odour, as discussed in Section 3.2.4.

TRS control measures for recovery boilers include good process control of variables such as combustion air, turbulence, rate of liquor feed, liquor spray pattern, liquor spray droplet size and excess oxygen in the flue gas.

Overloading the furnace (solids firing rate) has an adverse effect on the quantity of hydrogen sulphide produced because the supply of excess combustion air is usually restricted when the boiler is overloaded. Stringent emissions regulations in the U.S. have pretty much eliminated this practice. Excessive carryover of liquor spray particles restricts the maximum gross heat load per unit of boiler cross section to about 1,100,000 Btu/h/ft.^{2} (Blackwell 1994). To minimize TRS emissions, the loading needs to be somewhat lower. Springer 1986 reports that the dry solids load should be about 14,700 kg/m^2/d equivalent to around 750,000 Btu/h/ft^2. Blackwell (1994) believes this value is unnecessarily low. The solids content of black liquor should be at least 62% (Smook 1989).

H_2S is released at the char bed level where conditions are oxygen deficient. More combustion air is provided at elevations above the char bed to complete the combustion of the volatiles, including H_2S. An excess of oxygen and good mixing of the air and furnace gases are required. The better the mixing, the lower the quantity of excess air required. Typically, the oxygen concentration in the flue gas leaving the economizer should be between 2.0 to 3.5% (10-15% excess air) (Blackwell 1994) to ensure complete combustion. Complete combustion will also minimize VOC emissions from this source. If there is less than 2% oxygen in the flue gas leaving the economizer, there will be unburned matter in the flue gas including H_2S. However, operating with excess oxygen will also increase the emissions of combustion products (NO_x).

Increasing the primary air temperature will decrease the release of H_2S from the char bed resulting in reduced H_2S emissions.

Recovery furnaces built prior to 1965 have direct contact evaporators and therefore cannot achieve TRS emissions less than 5 ppm. Twenty ppm is considered achievable, with 2-stage black liquor oxidation (U.S. EPA 1993a).

The low odour recovery boiler was developed in 1967 and is a well proven technology. In low odour boilers, there is no direct-contact evaporation of liquor prior to firing. Low odour recovery boilers are highly reliable, with little down time, except as part of scheduled mill outages. With proper boiler operation, there is no need for a scrubber as TRS emissions will be less than 5 ppm (usually in the 1 to 5 ppm range). If they cannot achieve 5 ppm, it is likely that the furnace is being overloaded or operated inefficiently (i.e. 10 to 15% excess air should be supplied, providing 2 to 3% oxygen in the flue gas at the economizer exit).

In the last 10 years, there have been many advances in the combustion technology of recovery boilers, specifically in the manner in which air is delivered to the boiler. Adequate air supply and good mixing within the combustion chamber will decrease TRS emissions, as TRS results from incomplete combustion.

H.A. Simons et al. 1994 reported the following uncontrolled emission factors from recovery boilers:

Source	Pollutant	Quantity
U.S. EPA (direct-contact)	TRS	6 kg H_2S/ADt (519 ppmv @ 8% O_2)
	MM, DMS, DMDS	1.5 kg H_2S/ADt (130 ppmv @ 8% O_2)
measured	TRS	8-80 ppmv TRS @ 8% O_2
U.S. EPA (low odour)	TRS	0.05 kg H_2S/ADt (4.3 ppmv @ 8% O_2)
measured	TRS	<5 ppmv @ 8% O_2

ADt - air dry tonne pulp

3.2.8 Smelt Dissolving Tank

Smelt is discharged from the recovery boiler into the smelt dissolving tank. It is generally dissolved in weak wash from the lime mud washing process to form green liquor. The green liquor is clarified to remove solids (dregs). The green liquor then goes on to the causticizer to be combined with quick lime to form white liquor.

H_2S is emitted from the smelt at the spout through which the molten smelt flows. To a lesser extent, H_2S is also emitted from the surface of the green liquor. The equilibrium concentration for H_2S over smelt is around 500 ppm while the equilibrium constant for H_2S over green liquor is around 15 ppm (Fredrick 1986 as cited by Blackwell 1994). In addition, methyl mercaptan, dimethyl sulphide and dimethyl disulphide are emitted from the green liquor. These emissions, and the emission of hydrogen sulphide from the green liquor, depend on the concentrations of the compounds in the process condensates and the amount of process condensate used in recausticizing.

Air emissions from the smelt tank are usually passed through a venturi scrubber or a demister. A venturi scrubber can remove particulate, hydrogen sulphide, methyl mercaptan and other contaminants if an alkaline solution is used as the scrubbing liquid (often weak wash). It is reported that a demister or mist pad can remove moisture, particulate and TRS (Springer 1986). However, its effectiveness of removing TRS is expected to be limited (Blackwell 1994). Using contaminated condensate in either the smelt tank, or the scrubber, introduces more TRS which can then be stripped into the gas phase and released along with VOC emissions from the smelt dissolving tank. Use of well stripped condensate will minimize these emissions.

TRS removal efficiencies using weak wash as the scrubbing liquor in a venturi scrubber are reported to be about 80% (H.A. Simons et al. 1994) resulting in TRS emissions of approximately 0.008 kg H_2S/t Black liquor solids (BLS). Adding a packed bed section to the scrubber can increase the removal rate up to approximately 90 to 95% but not below 10 to 20 ppm. Using fresh caustic as the scrubbing medium can reduce TRS emissions to 2 to 5 ppm.

Average TRS emissions from a smelt dissolving tank are approximately 7 mg/kg BLS. The U.S. EPA AP42 (as cited in H.A. Simons et al. 1994) reports H_2S emissions of 0.1 kg H_2S/ADt pulp (0.06 kg/ADt BLS) and total methyl mercaptan, dimethyl sulphide and dimethyl disulphide emissions of 0.15 kg as H_2S/ADt pulp (0.1 kg/ADt BLS). These emission rates probably correspond to the use of process condensates with a relatively high level of TRS contamination in recausticizing (Blackwell 1994). For this type of situation, an alkali scrubber would remove only about 50% of the total TRS.

There are two principal control options for TRS from the smelt dissolving tank:

1. the use of fresh water as wash water in recausticizing, instead of contaminated condensates, especially around the lime mud precoat filter and on the lime kiln scrubber;

2. the use of fresh caustic as the scrubbing medium in the smelt dissolving tank scrubber, instead of weak wash.

There is some scope for using process condensates in recausticizing, provided that they have low levels of TRS. This could be accomplished through good segregation techniques and by thorough stripping of foul condensates. The foul condensate stripper should remove 95 to 98% of the TRS. This may require acidification of the feed. Process condensate low in TRS could be used at the lime mud washer, for dregs washing, grits washing and to dilute clarifier underflows. Process condensate should not be used in the kiln scrubber or around the lime mud precoat filter unless it is particularly low in TRS.

3.2.9 Lime Mud Washing

Lime mud washing on the precoat filter ahead of the lime kiln can be accomplished with clean water or with condensate from the evaporator system. Use of contaminated condensate will introduce reduced sulphur compounds and VOCs into the lime mud, which will be released in the lime kiln. Use of clean wash water, a high degree of lime mud washing and obtaining a relatively dry filter cake with about 80% solids will help minimize the reduced sulphur compounds and VOCs introduced into the lime kiln.

Sodium compounds such as sodium sulphide (Na_2S) cause problems in the lime kiln. The lime pellets may grow to form large "balls" or adhere to the brick to form "rings". Residual sodium sulphide in the lime mud also contributes to TRS emissions from the lime kiln. The lime mud is fed to the colder end of the kiln and as the mud dries, the action of carbon dioxide on the sodium sulphide causes hydrogen sulphide to form. Some of the hydrogen sulphide reacts with oxygen and is burned, but this reaction is limited to about 50% (Blackwell 1994) by the colder temperatures at the feed end of the kiln.

These TRS emissions can be reduced by improving the washing of the lime mud, to decrease the washable sodium sulphide concentration to less than 0.01 wt.% in the mud. At this level, the

contribution of the residual sodium sulphide to kiln TRS emissions is limited to about 5 ppm (Blackwell 1994).

Various measures to increase the efficiency of lime mud washing are:

1) *Maximize the slurry concentrations* in the underflows from the white liquor clarifier (or pressure filter) and the lime mud washer (or pressure filter). This is mainly an operational issue.

2) *Use clean wash water instead of contaminated condensate* at the last washing point, the lime mud precoat filter. Use of contaminated condensate with 15 ppm TRS will increase kiln TRS emissions by about 2 ppm.

3) *Increase the temperature of the wash water* on the lime mud precoat filter to about 80°C. This improves the performance of the filter.

4) *Apply lime mud recycle* to improve lime mud washing. This increases the slurry concentrations in the underflows from the white liquor clarifier and lime mud washer. It also increases the solids content of the cake on the lime mud precoat filter.

5) *Install a large lime mud precoat filter* to obtain a high solids content for the discharge cake, around 80 wt%. The large filter also facilitates oxidation of sodium sulphide in the cake, by the air drawn through the cake. With small filters, some oxidation of sodium sulphide can be accomplished by adding hydrogen peroxide to the mud filter. One mill with a centrifuge, installed an air sparger in the lime mud storage tank to oxidize sodium sulphide.

The five measures listed above are all complementary and additive. These measures are also complementary with efforts to decrease TRS emissions that originate in the kiln from incomplete combustion of natural gas, fuel oil, non-condensible gases, stripper vent gas, etc. In addition, increasing the lime mud washing capacity will decrease TRS emissions.

All of these techniques have been proven at full scale, are reliable with little down time and could be used in Ontario kraft mills.

3.2.10 Lime Kiln

Lime mud is calcined to quick lime for use in the recausticizing area. The calcination reaction usually takes place in the lime kiln and involves drying the lime mud, raising the temperature to approximately 820°C (Smook 1989) and maintaining the high temperature for sufficient time for the reaction to take place. The lime mud is passed, counter-currently, in the lime kiln with hot combustion gases. The hot end of the lime kiln is approximately 1,150 to 1,250°C (Smook 1989). The gases leave the kiln at the cold end, and must be scrubbed to remove lime mud dust before discharge. This is usually accomplished with a venturi scrubber. Low sulphide concentrations in the make-up water to the scrubber reduces TRS from the gas stream. Use of contaminated condensate for scrubber make-up water increases kiln TRS emissions relative to fresh water make-up.

In the kiln, TRS compounds can be oxidized at temperatures above 400 to 500°C with sufficient residence time. H.A. Simons (1994) reports that short lime kilns have lower TRS emissions because a higher average temperature is required for the calcining reaction. However, the amount of Na_2S in the mud fed to the kiln is much more important in determining TRS emissions than the kiln length (Blackwell 1994). To minimize Na_2S in the mud fed to the kiln, one needs good lime mud washing, and oxidation of Na_2S on the lime mud filter. Kilns that have cooler wet end temperatures will tend to release more H_2S because it is volatilized without burning. Process controls that maintain a desirable oxygen content of the gases leaving the kiln and adequate temperature at the point of exhaust discharge will ensure complete combustion and abate TRS emissions. Automatic control systems can be purchased for this purpose.

Excess oxygen may be provided by increasing air flow or by providing pure oxygen (molecular oxygen) as a portion of the air. Cold end oxygen concentrations greater than 4% minimize TRS emissions (Springer 1986). Operating with excess oxygen could, however, result in higher emissions of combustion products (NO_x). If the kiln is operated over capacity, it becomes difficult to provide enough air to get sufficient excess oxygen needed to destroy all TRS emissions in the kiln exhaust gases.

Proper burner design and good kiln operation can help to keep TRS emissions to less than 5 ppm.

Good kiln operating measures as defined by the National Council for Air and Stream Improvement (NCASI) include:

- raising the temperature of the cold end of the kiln;
- high O_2 (about 4%) content of the gases leaving the kiln;
- low sulphide content of the lime mud feed to the kiln; and
- low sulphide content for the scrubber water.

According to U.S. EPA (1979), TRS emissions from the lime kiln range from 0.01 to 2 g/kg ADP (4 to 842 ppm) depending upon the operating conditions, with an average of 0.4 g/kg ADP (168 ppm). This is very high by today's standards. U.S. EPA (1979) discusses a scenario in which the emissions from an uncontrolled lime kiln can be reduced to 40 ppm by adding more air and raising the cold end temperature by 100°F. Improved process controls can reduce emissions to 10 to 20 ppm. Caustic scrubbing of exhaust gases can reduce emissions to below 8 ppm. Improving the lime mud washing system and introducing process control on existing lime kilns have provided emission reductions of more than 80% (U.S. EPA 1979). It may be difficult to obtain low TRS emissions (10 to 20 ppm) if the kiln is overloaded and insufficient oxygen is available. Emissions of 40 ppm may be the lowest that is achievable in an overloaded kiln.

3.2.11 Scrubbers

Scrubbers can be used to decrease TRS emissions from various non-condensible gas (NCG) streams, the smelt dissolving tank, the recovery boiler stack, lime kiln stack etc. The choice of scrubbing liquid can impact TRS emissions. Caustic is the most obvious scrubbing medium, since the bleed stream, or liquid output stream from the scrubber can be used as make-up to the liquor cycle. However, since the requirements for sodium make-up to the liquor cycle are limited, fresh sodium caustic use on scrubbers has to be limited. This issue can be avoided by using oxidized white liquor in the scrubber; the scrubber bleed, containing the oxidized white liquor, could then be used in the oxygen delignification stage of the bleach plant. A disadvantage of this approach is that, while caustic absorbs hydrogen sulphide and methyl mercaptan, it does not absorb dimethyl sulphide and dimethyl disulphide. Depending upon the concentrations of the

individual TRS species in a given gas stream, a caustic scrubber can have a TRS removal efficiency in the range 50 to 90% (Blackwell 1994). For example, the TRS in the smelt dissolving tank vent is mainly H_2S so TRS removal with caustic is good, providing the pH of the scrubbing solution is kept above 11.5. For vent gas from the black liquor storage tanks and brownstock washer filtrate tanks, or brownstock washer hood ventilation air, the TRS has a considerable organic sulphide content. In this case, the TRS removal efficiency with caustic will be limited to around 50%.

When the TRS has a high organic sulphide component, the TRS removal efficiency can be increased by scrubbing with an oxidizing agent, such as sodium hypochlorite. The TRS removal efficiency is then about 90%. With sodium hypochlorite scrubbing, there will be some emission of chlorine. Also, if the bleed from the scrubber is added to the liquor cycle, the chlorine content is not advantageous as it leads to sodium chloride accumulation in the liquor cycle.

For lean gas from the tank vents, the sewer vents, the brownstock washer hood vents, etc., incineration is the preferred treatment, because all of the TRS is destroyed. Nonetheless, there are some situations where practical considerations preclude incineration (i.e. high moisture content). In these situations, scrubbing is considered to be the preferred alternative.

Caustic scrubbing of incinerator exhaust gases controls SO_2 emissions. Caustic scrubbing of the flue-gas from a recovery boiler with a direct contact evaporator controls H_2S and mercaptan which are the principle emissions, but not dimethyl sulphide and dimethyl disulphide. A chlorine-caustic solution may be used as an alternative scrubbing liquid in which the chlorine oxidizes the dimethyl sulphide and dimethyl disulphide.

3.2.11.1 Recovery Boiler Scrubbers

Scrubbers have been used to treat recovery boiler flue-gas at a few Canadian mills, including the mill at Smooth Rock Falls, over the last 10 to 15 years. In most cases, the intent is to remove particulate emissions. There is some TRS removal as some caustic is used. However, to achieve efficient TRS removal, activated carbon has to be added to the scrubbing solution and the solution has to be recirculated through an oxidizer. This allows most of the H_2S to be removed at a pH of around 9, thereby avoiding absorption of carbon dioxide from the flue-gas. CO_2 absorption would increase caustic consumption to an unacceptable level.

3.2.11.2 Smelt Dissolving Tank Scrubbers

Traditionally, weak wash has been used in the dissolving tank vent scrubber to remove particulate. The TRS compounds in the dissolving tank vent gas originate mainly from the sodium sulphide in green liquor in the smelt dissolving tank. Scrubber weak wash also contains sodium sulphide. When using weak wash as the scrubbing medium, TRS emissions from the smelt dissolving tank vent gas are in the range of 10 to 20 ppm. An improvement can be obtained by using a 5 wt.% caustic solution as make-up to a recirculating stream, and avoiding any use of weak wash. In this way, TRS emissions can be decreased to about 2 to 5 ppm, provided that there are minimal organic sulphides in the weak wash. When sodium hydroxide (caustic) is used in the smelt dissolving tank scrubber, the scrubber bleed is added to the liquor cycle, provided that this bleed can displace other caustic required in the liquor cycle. This is likely to be the case at most Canadian kraft mills, since the amount of caustic make-up for a recirculating smelt dissolving tank scrubber would be small — about 4 U.S.gpm of a 5% caustic solution (Blackwell 1994). If this caustic can displace other caustic already being added to the liquor cycle, there will be no additional cost. However, if no such displacement is possible, the cost for the caustic would be about $100,000/year.

Caustic is being used in the dissolving tank scrubber, instead of weak wash, at some U.S. mills. Smelt dissolving tank scrubbers have always had reliability problems due to plugging. These problems are not resolved by replacing weak wash with caustic.

3.2.11.3 Lime Kiln Scrubbers

Newer lime kiln designs have an electrostatic precipitator to remove particulate from the kiln flue-gas. Old kiln designs have scrubbers. If contaminated condensate is used as the make-up water for lime kiln scrubbers, most of the TRS in the contaminated condensate will be transferred to the kiln flue-gas as an air emission. This transfer can be minimized by selecting a process condensate with a low concentration of TRS - for example, well-stripped condensate. However, the issue is avoided totally by using fresh water as make-up to the scrubber. This is done in most U.S. mills. Use of fresh water also avoids any VOC emissions that can result from using process condensates in the kiln scrubber.

3.2.12 Condensate Stripping

Foul condensates are produced in the digester system and the multiple-effect evaporator. These foul condensates contain high concentrations of reduced sulphur compounds.

About 10% of the TRS compounds that enter an aerated lagoon with the mill effluent are stripped to the atmosphere. TRS emissions from biological treatment of mill effluent are addressed by collecting the foul condensates within the mill and stripping them in a steam distillation column. The TRS compounds are isolated in a small stripper vent gas flow, which is incinerated. The stripped condensate is re-used in the mill process, either in brownstock washing or recausticizing. The vent gases from the stripper are usually incinerated in the lime kiln or the power boiler. This practice also minimizes VOC emissions.

Stripping of the sulphur and organic compounds from the foul condensate using a steam stripper, prior to its use in recausticizing and brownstock washing, will reduce TRS emissions. A steam stripper is essentially a multi-stage distillation separation device using direct steam as the heat source. The volatile compounds (i.e. TRS) are vaporized and the exiting gases are incinerated in an on-site incineration device. TRS removal efficiencies of up to 94% have been reported (U.S. EPA 1993a).

Steam stripping has been conventional technology for about 20 years. Most of Ontario's kraft mills have a foul condensate stripper; many of these are designed for 5 to 8% steam on condensate to remove TRS only; BOD removal is limited. In some cases, the TRS removal efficiency has room for improvement. By increasing the steam usage to 20% on condensate, most of the methanol, ethanol and acetone are removed, thereby eliminating most of the BOD in the foul condensate and controlling VOC emissions from the biological treatment system.

3.2.13 Vent Sources

Vent sources such as the brownstock washers, the smelt dissolving tank, the deckers, the screens, the black liquor storage tanks, the tall oil tank, etc. can be controlled by collecting these emissions and routing them to a combustion device.

3.2.13.1 Existing Combustion Devices

The vent gases in a kraft pulp mill can be divided into two categories. High concentration low volume (HCLV) gases (such as emissions from the digester area, the condensate strippers, the evaporators etc.) and low concentration high volume (LCHV) gases (such as emissions from the brownstock washers, the pulp knotter, the black liquor storage tank venting, the brownstock washer filtrate tank venting, the continuous digester chip bin venting, the sewer venting, the washer seal tanks etc.). HCLV gases can often be used as an auxiliary fuel (the heat content must be approximately 100 Btu/Sft.^{3} or greater) (AWMA 1992) and are generally burned in lime kilns, recovery boilers, power boilers or stand-alone incinerators. LCHV gases are generally burned in boilers which can accept large volumes of gas. If sufficient oxygen is present in the gas stream (approximately 20%), the gas stream may be used as supplemental combustion air (U.S. EPA 1993a).

Generally, at most existing pulp mills, the HCLV gases are collected and burned in the lime kiln. Consequently, the sources remaining which may have the greatest impact at off site receptors are the LCHV sources. In the United States, the current regulatory approach is to collect these emissions (where technically feasible) and route them to either an existing combustion device or to a dedicated combustion device. These combustion devices generally have a destruction efficiency of greater than 98% for hazardous air pollutants (HAPs), including TRS.

Incineration in the Lime Kiln

The lime kiln is generally used for combustion of HCLV gases such as digester relief gases, digester blow gases, evaporator vent gases, stripper vent gases. These are used as auxiliary fuel. The temperature in the lime kiln is approximately 950-1,250°C. These high temperatures make it very efficient in destroying HAPs, with control efficiencies reported to be greater than 98% (U.S. EPA 1993a). This is proven technology that has been used for 20-30 years in the U.S. and is probably practiced at all Ontario kraft mills as well.

At some mills, there is a concern that incineration of HCLV and stripper vent gas in the lime kiln contributes to the formation of rings and balls in the kiln. This can be moderated by improving the combustion stability in the lime kiln.

There is a potential for SO_2 emissions from the lime kiln to increase due to the oxidation of TRS compounds. However, this will be partially offset by some of the SO_2 reacting with lime to form sodium sulphate and calcium sulphate.

Incineration in the Power Boiler

One advantage in using the power boiler over the lime kiln for combustion of HCLV gases is that the power boiler has less down time. In addition, it can handle larger volumes of vent gases for use as combustion air if sufficient oxygen is present or the vent gas can be used as auxiliary fuel if the heat content is sufficient. The high moisture content of the gases could be taken advantage of to help dry wood waste on the grate, as drying rates actually increase as the moisture content of the gas increases, at higher temperatures. Power boilers which operate at greater than 1,000°C have reported destruction efficiencies for HAPs of more than 98%. Power boilers with capacities greater than or equal to 150 million Btu/h will operate at these high temperatures (U.S. EPA 1993a). If wood waste is burned in the power boiler, some of the SO_2 from burning the TRS will be absorbed on the ash, but the potential for absorption is limited. Consequently, burning TRS in the power boiler results in SO_2 emissions. It should be technically feasible to burn HCLV, LCHV gases and stripper vent gas (i.e. digester relief and blow gases, turpentine recovery system NCGs, evaporator emissions and pulp washer hood vent gases) in power boilers at most Ontario kraft mills. However, because of the resulting formation of SO_2, corrosion of the combustion air heater may be accelerated somewhat. SO_2 emissions could be reduced by scrubbing stripper vent gas with white liquor prior to incineration in the power boiler. This has not been tried, but should be feasible.

Incineration in the Recovery Boiler

LCHV gases can be burned and destroyed in the recovery boiler with a destruction efficiency of at least 98% (at 1000°C). Vent gases with high concentrations of turpentine are not generally burned in the recovery boiler because of the risk of explosion. Stripper vent gases are also not suitable for burning in a recovery boiler due to the high moisture content. Moisture in the vent gas stream is a potential hazard because it may react violently with the smelt bed (U.S. EPA 1993a). This concern can be addressed through proper design and operation, but to be safe, concentrated non-condensible gases and gases with a high water vapour content should be

avoided. Due to safety concerns, there will be continued reservation by boiler operators to introduce gas streams with a high moisture content into a recovery boiler.

When TRS gases are burned in the recovery boiler, the TRS is oxidized to SO_2. The SO_2 reacts with the sodium carbonate fume to form sodium sulphate fume. The fume is captured in the precipitator and recycled to the liquor fed to the furnace. In the furnace, the sodium sulphate is reduced to sodium sulphide. In this way, the sulphur in the TRS gases is incorporated into the smelt, so sulphur dioxide emissions do not increase.

It has been recommended that washer gases be incinerated only in the secondary or tertiary air zones of the furnace to keep moist air away from the smelt bed (U.S. EPA 1979). This practice could affect the operation of the recovery furnace because the flexibility of air flow rate to each zone is limited.

Additional Considerations

Excessive moisture can cause loss of flame in incinerators. Therefore, in some cases it may be important to remove moisture from the vent streams prior to being sent to the primary control device. Condensation is the most common method of removing moisture. It has been reported in the United States that some mills are using entrainment separators for moisture removal. The condensate stream will be discharged to a sewer. The impact on the wastewater treatment has not been determined as it is beyond the scope of this study.

Condensation can also be used to remove volatile HAPs such as turpentine from vent streams. High levels of turpentine present in the vent stream could result in a concentration above the lower explosive limit (LEL) and could, therefore, be a hazard. This is of greatest concern in the recovery boiler and lime kiln, because they are critical to mill operation. Turpentine can be recovered from digester blow gases using condensation. This is a marketable by-product. Other potentially-explosive organic compounds can also be removed from vent streams using condensation.

Explosion-proof electrical devices may be necessary, as well as other safety devices such as flame arrestors.

3.2.13.2 Thermal and Catalytic Incineration

Thermal Incineration

Positive oxidation of TRS by thermal incineration will occur at approximately 650°C to 816°C (Smook 1989). Some combustion of H_2S is intiated at temperatures above 400 to 500°C (Blackwell 1994). The current U.S. EPA regulations require incineration at 650°C for 0.5 seconds. For VOC destruction, an incinerator temperature of 1,100°C with a residence time of 1 second will give 98% or greater control (U.S. EPA 1993a). Thermal incinerators can be designed to treat both LCHV and HCLV vent streams. Streams with a heat content less than 100 Btu/Sft^3 (i.e. vent streams from washers) will require supplemental fuel to maintain the combustion temperature (U.S. EPA 1993a). Package single-unit thermal incinerators are available which can handle flow rates of 14 to 1,400 Nm^3/min (U.S. EPA 1993a). A control efficiency greater than 98% can be realized with proper incinerator operation (excess air etc.) and sufficient residence time and combustion temperature.

An incinerator will release typical combustion products such as NO_x, SO_x and CO. A caustic scrubber is often installed after a stand-alone incinerator to control SO_2 as discussed in Section 3.2.10.

Generally, incinerators at pulp mills are not designed with heat recovery because the value of the heat that could be recovered does not justify the capital cost.

Catalytic Incineration

Catalytic incineration takes place at a lower temperature (approximately 300 to 500°C). Capital investments in catalytic systems are higher than thermal systems but the operating costs can be much less (Smook 1989). Fouling agents in the gas stream may reduce the functionality of the catalyst. Catalytic incinerators are not commonly used in the pulp and paper industry because of the availability of alternative on-site thermal incinerating devices (lime kiln, power boiler, recovery boiler).

Flares

Flares are used at a few facilities in the pulp industry as backup systems to primary combustion devices such as lime kilns. Flares are not attractive because there is often not sufficient heat content in the vent stream for proper operation and auxiliary fuel has to be used. Because of the limited retention time in the flare, the TRS destruction efficiency is limited to 50 to 75% (Blackwell 1994). Destruction efficiencies of 98% or greater for VOCs have been reported (U.S. EPA 1993a) for properly operated flares; it is doubtful that flares are this effective on TRS.

3.2.13.3 Alternative Controls

Venting TRS emissions with the bleach-plant chlorination or chlorine dioxide stage washer vent gases will chemically oxidize the sulphur compounds in the bleach plant scrubber (AWMA 1992).

3.2.14 Fugitive Emissions

In addition to the sources mentioned in the previous sections, pulp mills also have numerous fugitive sources. Some fugitive sources may include leaking flanges, leaking pump seals, building ventilation, open sewers, spills and the wastewater collection system (effluent trenches and wastewater lagoons). Estimates of emission rates from these sources are difficult to quantify and little work has been done to characterize the emissions (H.A. Simons 1994), but they could be significant. An effective leak detection and repair program, and spill control, can minimize many of the fugitive emissions (i.e., leaking seals, flanges, etc.)

Black liquor losses and sewered process condensates (foul and contaminated) result in emissions from the wastewater collection system. TRS and VOC emissions may be released from pumphouse vents, open sewers, clarifiers and ultimately from the lagoon. Sandwell (1993) estimates that 10% of TRS compounds that enter an aerated lagoon are stripped to the atmosphere, 60% are removed by biological processes, and 30% remain in the effluent leaving the lagoon. Sandwell (1993) also reports a VOC emission rate of 1.5 kg VOC/ADt from an aerated lagoon. H.A. Simons (1994) reports emission levels ranging from 0.1 to 0.6 kg H_2S/ADt with a typical discharge level of approximately 0.4 kg H_2S/ADt. The U.S. EPA (1993a) recommends designing wastewater treatment operations in such a way as to reduce the amount

of contact between the contaminated wastewater and the ambient air. Use of covers and water seals on collection system components as well as hard-piping the wastewater to the treatment system provides the best control. TRS and VOC emissions from the treatment system can also be moderated through pH control and oxidation of the waste water.

Condensate from gas conditioning equipment can be disposed of to the wastewater treatment system or can be stripped, if there is a steam stripper.

Domtar (1995) stated that recent investigations do not support the conclusion that VOC emissions from biological treatment systems will be controlled by steam stripping. Domtar (1995) stated that activated sludge process studies have shown that methanol, the biggest component of condensate VOCs, is almost entirely metabolized by the system's biomass.

3.3 Regulatory Approaches to Controlling TRS Emissions

The emission controls described in the previous sections are generally considered the Best Available Control Technologies (BACT). Table 3.3 presents the RACT/BACT/LAER entries for pulp mill TRS control in the United States for 1990, 1991, 1992 and 1993. Table 3.3 shows that the controls discussed in Section 3.2 are currently in use in the United States and are considered BACT. The following sections describe a) the U.S. EPA approach to reduce mass emissions by implementing source performance standards and b) the current Ontario point of impingement (POI) limit approach.

3.3.1 U.S. EPA Approach - Mass Emission Reduction - Large Sources

The U.S. EPA considers mass emission rates from various systems within the plant and sets limits based on available technology (described below). The results of this regulatory requirement are published for approved facilities in the U.S. EPA RACT/BACT/LAER Clearinghouse listings. For the pulp and paper industry, the following controls will reduce the total mass loading to the environment. However, these U.S. controls may not ensure that an individual pulp mill in Ontario will meet any future POI limit or even the current POI limit. At most pulp mills in Ontario, these U.S. measures have already been adopted. If not, the following steps should be undertaken:

1) The pulp mill should be equipped with a low odour recovery boiler (indirect-contact evaporator) or if the evaporators are direct-contact, a black liquor oxidation system should be added.

2) The recovery boiler and lime kiln should be run with sufficient excess air, should not be overloaded, should have adequate combustion air mixing and should have a sufficient combustion temperature.

3) Wash water used in brownstock washing and recausticizing, as well as water used in scrubbers should be fresh water or process condensate that has been well stripped. If necessary, a foul condensate stripper should be installed.

4) Emissions from digesters, vent and blow gases, multiple-effect evaporator systems, turpentine recovery systems, hotwells, foul condensate stripping systems and other HCLV emissions should be collected and emissions routed to the lime kiln for incineration. This is likely already done at most facilities.

5) Smelt dissolving tank emissions should be reduced by using caustic make-up for the scrubber, instead of weak wash.

6) An emergency venting plan for NCGs should be in place. For example, if the lime kiln is normally used for incineration of these gases, the emissions should be routed to an alternative incineration source, or at the very least diverted to the recovery boiler stack to ensure dispersion and protection of mill workers when the lime kiln is not operating.

3.3.2 U.S. EPA Approach - Mass Emission Reduction - Small Sources

Once the pulp mill has implemented the controls described above, the next priority should be to control the lower concentration fugitive sources such as the brownstock washers, the knotters, the deckers, the screeners, the black liquor tanks, the recausticizing tanks, the tall oil plant, etc. Regulations currently being introduced in the United States for new sources recommend collection of emissions from these sources for combustion in an existing combustion device or in a dedicated thermal incinerator or flare. The most commonly used existing combustion device

is the power boiler, although recovery boilers are also used. It may not be feasible to collect and treat the emissions from all of these sources (specifically brownstock washers and knotters), but this must be determined on a case-by-case basis.

Current U.S. EPA NSPS Regulations and existing mill guidelines for TRS emissions from Kraft Pulping Facilities are as shown in Table 3.4.

Table 3.4
U.S. EPA REGULATORY LIMITS

	New Source Performance Standards (NSPS)	Existing Mill Emission Guidelines
Kraft Digester	5 ppmv (10% O_2)[2]	5 ppmv (10% O_2)
Kraft Brownstock Washer System	5 ppmv (10% O_2)[1][2]	No Control
Multiple-effect Evaporator System	5 ppmv (10% O_2)[2]	5 ppmv (10% O_2)
Condensate Stripper System	5 ppmv (10% O_2)[2]	5 ppmv (10% O_2)
New, Modified or Reconstructed Kraft Digester System	5 ppmv (10% O_2)[2]	5 ppmv (10% O_2)
Recovery Furnace (new design)	5 ppmv (8% O_2)	5 ppmv (8% O_2)
Recovery Furnace (old design)	5 ppmv (8% O_2)	20 ppmv (8% O_2)
Cross Recovery	25 ppmv (8% O_2)	25 ppmv (8% O_2)
Black Liquor Oxidation System	5 ppmv (8% O_2)	No Control
Lime Kiln	8 ppmv (10% O_2)	20 ppmv (10% O_2)
Smelt Dissolving Tank	8.4 mg/kg BLS	8.4 mg/kg BLS

Note: [1] standard does not apply to facilities where implementation has been demonstrated not to be technically feasible or economically feasible
[2] recommended method of control is combustion in lime kiln, recovery boiler or incinerator at a minimum of 1200°F (650°C) for 0.5 seconds.
Source: U.S. EPA 1993a; Springer 1986.

The NSPS apply to new facilities or to existing facilities that have been extensively modified. Note that the regulations apply to systems as a whole. Individual emission points are not regulated separately. It is the assumption of U.S. EPA that all emissions from an operation have been collected together for treatment in a single unit. The preferred technology is combustion of the TRS into sulphur dioxide via the lime kiln, the power boiler, the recovery boiler or a

stand-alone incinerator. For existing mills, the goal is to reduce odour to an acceptable level, not to eliminate it (Springer 1986).

The emission standards shown in Table 3.4 are what the U.S.EPA would like to see for emissions from each of these sources. How the results are obtained are up to the individual pulp and paper company. For example, with a low-odour recovery boiler, the operator might just add enough excess air to achieve less than 5 ppm TRS, or they might improve the combustion air system to increase mixing so that more excess air is not required. To achieve the targets for some of the items, incineration will be required. The list does not include fugitive emissions. Table 3.5 provides control measures for some of the sources.

There are also State regulations for emissions from new pulping facilities. These are summarized in Table 3.5. Some limits are given as in-stack concentrations while others are based on a mass emission rate per unit of production.

One of the requirements of the U.S. EPA Clean Air Act Amendment of 1990 (Section 112(d)) is the development of National Emissions Standards for Hazardous Air Pollutants (NESHAP) for Pulp and Paper Production by 1997. In late 1993, proposed standards were released (U.S. EPA 1993d). These proposed standards cover both the water effluent and air emissions from the pulp and paper industry. Air emissions of volatile components such as turpentine and methanol from the pulping process, and chlorinated compounds from the bleaching process, are the main targets of these proposed standards. For the chlorinated compounds, an incineration device capable of 1,000°C with a retention time of 1 second is being proposed. No control would be required if the individual process emission points from enclosed process equipment have:

- a volumetric flow rate of less than 0.005 standard cubic metres per minute; or
- a mass flow rate of less than 0.230 kilograms of total Hazardous Air Pollutants (HAP) per hour; or
- a mass flow rate of less than 0.0010 kilograms of total HAP per megagram of air dried pulp.

Table 3.5
SUMMARY OF STATE REGULATIONS FOR EMISSIONS FROM PULPING FACILITIES

Process Unit	Emission Limits[1]	States Regulating	Method of Control
Kraft digester system	5 ppm of TRS 1.2 lb. TRS/ton ADP	ME, VA SC, GA, FL ID, IN, CA, MS, LA AL	Combustion Incineration Not specified Incineration
Kraft digester system/ multiple-effect evaporators	0.6 lb. TRS/ton ADP 20 ppm of TRS	MD PA	Not specified Not specified
Kraft multiple-effect evaporators	5 ppm of TRS	VA, ME FL, SC, GA MS, TN, LA, CA AL	Combustion Incineration Not specified Not specified
Kraft brownstock washer	5 ppm of TRS	ME[2] CA	Combustion Not specified
Kraft condensate stripper	5 ppm of TRS	VA, ME CA, LA SC	Combustion Not specified Incineration
Bleach plant	3 lb./h of Cl_2 0.2 lb./h of Cl_2 3 lb./h of ClO_2 0.1 lb. of ClO_2	ME GA ME GA	Not specified Not specified Not specified Not specified
Tall oil plant	0.5 lb. TRS/ton oil	FL	Incineration
Sulphite mills	9.1 kg TRS/ton ADP	NH	Not specified
Effluent ponds	50 ppm H_2S	MT	Not specified

Notes: [1] Key: TRS = Total Reduced Sulphur; ppm = parts per million; ADP = Air-Dried Pulp; Cl_2 = Chlorine; ClO_2 = Chlorine dioxide; H_2S = Hydrogen sulphide

[2] After January 1994.

Source: U.S. EPA 1993a.

3.3.3 Ontario Regulation 346

Ontario legislation requires emission sources to meet specific contaminant levels at the property boundaries or the maximum point of impingement (POI) (for TRS the current limit is 40 $\mu g/m^3$). The maximum POI is determined from the emission rates and dispersion modelling as specified in O.Reg. 346. While all facilities must meet the same standard, how each facility chooses to do so may be quite different due to site-specific factors.

Depending upon the location of the different emission sources with respect to the property line, the smaller low level sources could have the greatest impact on the ground level concentration. Therefore, to evaluate the cost of meeting a revised POI standard, it is recommended that each pulp mill be evaluated separately. It is further recommended to model in detail the air dispersion with the Industrial Source Complex (ISC)[2] model to determine which sources are the major contributors to the ground level concentration (GLC). These sources should be the first targeted for control.

For example, at Red Rock, according to the O.Reg. 346 modelling which was undertaken, the smelt dissolving tank vent is the largest contributor to the GLC at the property line, followed by the brownstock washer vents. At Rainy River (formerly Boise Cascade), the major contributors to the GLC, according to O.Reg. 346 modelling, are the effluent pump house, the smelt dissolving tank stack, the tall oil tank and the brownstock washers (note that the GLC contribution varies significantly between the two reports prepared by IMET 1990 and IMET-EER 1992).

The major contributors to GLC at a specific POI will likely be different at each facility. At Malette, for example, the old recovery boiler stack and the lime kiln are the major contributors to the GLC. The old recovery boiler is the direct-contact type and does not have a black liquor oxidation system. Installing a black liquor oxidation system at this facility may be a priority to reduce the GLC of TRS.

[2] The ISC model is recommended because many of the low-level sources must be modelled using a building wake effects algorithm, and the ISC model currently has such an algorithm proven for regulatory assessments.

3.4 TRS Emissions Controls at Pulp Mills

This section describes the facilities at the three kraft mills under study and their current TRS emission controls. The emissions inventory for Rainy River, Malette and Domtar are presented in Tables 3.6, 3.7 and 3.8, respectively. Table 3.9 compares the emissions at each mill to the U.S. EPA NSPS. The reported stack concentrations were corrected to the appropriate oxygen content for comparison.

3.4.1 Rainy River Forest Products Inc. - Fort Frances

Rainy River Forest Products Inc. (previously Boise Cascade) - Fort Frances produces approximately 550 ADt/day kraft pulp from 1,100 ADt/day of softwood chips. Approximately 85% of the chips are produced on-site, with the remainder purchased off-site. The data presented for this report (Table 3.6) were extracted from a report entitled *Process Air Emission Survey Boise Cascade Canada Ltd.*, dated March 1992, and prepared by Independent Measurement and Technology Inc. (IMET).

Brownstock Washers

The softwood chips are converted into pulp in one of six batch digesters. The digesters are emptied into a blow tank. The knots are removed in an enclosed deknotter.

The black liquor is washed out of the pulp in the enclosed vacuum type brownstock washers in a 3-stage counter-current process. The pulp is thickened over an enclosed decker which uses fresh water as wash water and stored in a brownstock high density storage tank. The decker is not vented. Washer filtrate is used in a counter-current operation with the strongest filtrate going to the evaporators as 15% weak black liquor. The washers are enclosed in a hood system which vents to a demister and then to the atmosphere. The TRS emission rate from this source is approximately 0.056 g/s (Table 3.6).

The vent gases from brownstock washing might be used as combustion air for incineration in the recovery boiler. The recovery boiler at Rainy River was designed to accept brownstock vent gases as incineration air. However, because of reported operational problems, this capability was removed.

Bleach Plant Scrubber

Pulp from the brownstock high density storage tank is bleached in a four-stage process. The first stage is known as the Dc stage which utilizes 70% chlorine dioxide and 30% chlorine. The second stage is an Eo stage or caustic extraction stage, supplemented with oxygen. The third stage is an H stage utilizing sodium hypochlorite, and the final stage is a D stage utilizing chlorine dioxide.

The emissions from the bleach plant washers are vented through a packed bed scrubber. The emission rate from the scrubber is approximately 0.04 g/s TRS (Table 3.6). Caustic extraction stage filtrate is used as a scrubber liquor with caustic added to maintain pH as required. It is a once-through process with the filtrate being discharged to the sewer after passing through the scrubber.

There is enough oxygen in this source that the vent gases could be used as combustion air for incineration, as an alternative to scrubbing. Packed bed scrubbers are susceptible to channelling and can become ineffective with time, but this can be addressed through proper design and changing the packing periodically.

Black Liquor Tanks/Multiple Effect Evaporators

Weak black liquor washed from the pulp is stored in two tanks, with air emissions (approximately 0.002 g/s TRS) vented to the atmosphere. Weak black liquor passes through a five effect condenser/evaporator system, which concentrates the liquor to strong black liquor (65% solids). Non-condensible gases are collected and incinerated in the lime kiln. Concentrated black liquor is stored in a tank (strong black liquor tank) which is vented to the atmosphere. The TRS emission rate is approximately 0.005 g/s. There are no add-on controls for these emission points.

The emissions from these tanks are of sufficient oxygen content to be used as combustion air for incineration.

Table 3.6

RAINY RIVER FOREST PRODUCTS INC. (Fort Frances) TRS Emissions (IMET 1992)

TRS Emission Source	Air Flow Rate (DSm^3/h)	Temp (°C)	Moisture Content (est.) (%)	Oxygen Content (1989) (%)	Stack Parameters		Type of Source	TRS Emission Rate - Current Controls (g/s)	TRS Concentration (ppm)	TRS Emission Rate (kg/Mg pulp)	Emission Control Device	Other Pollutants Measured
					Diameter (m)	Height (m)						
Brown Stock Washer Stack	48,000	34	3.1	20.7	1.1	28.8	virtual	0.056	3	0.0087	scrubber demister	CO
Weak Black Liquor Tank	180	66	20.0	20.2	vent	23.6	virtual	0.002	29	0.0003		CO
Strong Black Liquor Tank	180	66	20.0	19.7	vent	23.6	virtual	0.005	77	0.0008		CO
Impounding Tank Vent	1,400	2			vent	23.6	virtual	0.017	31	0.0026		
Bleach Plant Scrubber	25,000	38	9.0	20.6	1.1	35.8	virtual	0.039	4	0.0061	packed bed scrubber	CO
Recovery Boiler Stack	203,000	197	26.6	3.6	2.7	76.4	point	0.156	2	0.0246	low odour boiler 2 ESP's	SO_2, CO, NO_x
Smelt Dissolving Tank	21,000	68	36 [1]	20.6	1.5	56.9	virtual	0.162	20	0.0255	scrubber demister	SO_2, CO,
Lime Kiln Scrubber Stack	33,000	71	30.0	9.3	1.5	30.6	point	0.096	8	0.0150	venturi scrubber	SO_2, CO, NO_x
Tall Oil Scrubber Vent	1,800	42	15.0	16.0	0.5	17.2	virtual	0.005	7	0.0008	packed bed scrubber	SO_2, CO, NO_x
Clarifier Vents	530	34	11.0		vent	3.2	virtual	0.018	90	0.0029		
Effluent Pumphouse Vent	160	5	2.2	18.5	vent	9.3	virtual	0.075	1,207	0.0117	ring water spray	SO_2, CO, NO_x

Mill Capacity 550 Air Dry Tonnes Pulp/day
BLS - black liquor solids
DSm^3/h - dry standard cubic meters per hour
[1] error suspected - should be about 70%

Table 3.7

MALETTE KRAFT PULP AND POWER (Smooth Rock Falls) - TRS Emissions (Air Testing Services 1993, 1992)

TRS Emission Source	Gas Velocity (m/s)	Temp (°C)	Moisture Content (%)	Oxygen Content (%)	Stack Parameters		Type of Source	TRS Emission Rate - Current Controls (g/s)	TRS Concentration Rate (ppm)	TRS Emission Rate (kg/Mg pulp)	Emission Control Device	Other Pollutants Measured
					Diameter (m)	Height (m)						
Brown Stock Units 1&2[1]	19.1[4]			20.0	0.9	25	virtual	0.06	3.6	0.01		TSP, NO_x, CO, SO_2
Brown Stock Unit 3[1]	19.1[4]			20.0	0.9	25	virtual	0.93	67.7	0.20		TSP, NO_x, CO, SO_2
Old Recovery Boiler[2]	18.9	55.5	17.9	4.8	2.1	47	virtual	1.56	23.2	0.33	Cyclone Evap., ESP,packed bed scrubber (TRS)	TSP, NO_x, CO, SO_2
Smelt Dissolving Tank[2]	4.9	81.5	48.1	5.7	1.2	36	virtual	0.21	80.9	0.04	scrubber	TSP, NO_x, CO, SO_2
Lime Kiln with ESP[1]	14.1	168.7	28.3	8.0	0.9	33	point	0.05	10.0	0.01	high eff ESP lime mud wash	TSP, NO_x, CO, SO_2
New Recovery Boiler[3]	14.2	178	31.5	5.3	2.4	68	point	0.02	0.4	0.003	ESP; dynamic scrubber	TSP, NO_x, CO, SO_2

Sources:

[1] Data from IMET 1993, January

[2] Data from IMET 1992, June

[3] Data from BOVAR-CONCORD Environmental 1994

[4] Data from Concord 1993, February

Notes:

* Replaced with ESP in 1993

Mill Capacity 411 Air Dry Tonnes Pulp/day

1. New recovery boiler comissioned in 1993 and reduced load on old recovery boiler
2. brownstock washer emission rate dropped to 0.03 g/s - reported by Concord 1993
3. Reported emission rates form year to year very variable

BLS - black liquor solids

ESP - electrostatic precipitator

Table 3.8

DOMTAR PACKAGING - RED ROCK MILL TRS Emissions (Domtar 1988)

TRS Emission Source	Air Flow Rate (DSm^3/h)	Temp (°C)	Moisture Content (%)	Oxygen Content (%)	TRS Emission Rate (g/s)	TRS Concentration (ppm)[1]	TRS Emission Rate (Kg/Mg pulp)	Emission Control Device	Stack Parameters		Type of Source
									Diameter (m)	Height (m)	
No. 8&9 M&D Washer Hood Vent	16,560	41	8	20	0.027	4.2	0.0028			24	virtual
No 10 M&D Washer Hood Vent	15,120	21	3	20	0.028	4.8	0.0029			24	virtual
M&D Foam Tank Vent	504	63	20		0.022	114.0	0.0023			24	virtual
No. 5&6 Hardstock Washer Hood	12,240	36	6	20	0.008	1.7	0.0008			24	virtual
No. 7 Hardstock Washer Hood Vent	28,080	30	4	20	0.039	3.6	0.0040			24	virtual
Hardstock Foam Tank Vent	828	63	20		0.034	105.0	0.0035			24	virtual
Turpentine Decanter Vent	11	75	38		0.120	28,700.0	0.0123			24	virtual
Recovery Furnace Stack	147,600	183	24	4.3	0.670	12.0	0.0689	low odour design precipitator	3.23	73	point
Smelt Dissolving Tank Vent								wet scrubber			
With Concentrator	27,360	75	38		1.370	130.0	0.1409			50	virtual
Without Concentrator	27,360	75	38		0.560	53.0	0.0576			50	virtual
Green Liquor Clarifier Vent	108	64	25		0.001	14.0	0.0001			21	virtual
No. 1 Causticizer Vent	22	95	85		0.0003	41.0	0.00003			15	virtual
No. 3 Causticizer Vent	108	88	66		0.002	37.0	0.0002			15	virtual
Lime Mud Filter Hood Vent	3,960	34	3		0.001	0.6	0.0001			21	virtual
No. 2 Lime Kiln Stack	30,240	77	42	5	0.740	64.0	0.0761	venturi scrubber	1.98	46	point

Mill Capacity 840 Air Dry Tonnes Pulp/day

BLS - black liquor solids

[1] dry basis

Table 3.9

Comparison of Pulp Mill Emissions with U.S.EPA NSPS and Existing Mill Emission Guidelines

Source	U.S.EPA NSPS		U.S. EPA Existing Mill Guidelines		Rainy River		Malette		Domtar	
	Concentration	Units	Concentration	Units	Source	Concentration	Source	Concentration	Source	Concentration
Kraft Digester	5	ppmv @ 10% O_2	5	ppmv @ 10% O_2	NE		NE		NE	
Kraft Brown Stock Washer System (Emissions incinerated)	5	ppmv @ 10% O_2	No control		Brown Stock Washer System	~	Brown Stock Units 1&2	~	No. 8&9 M&D	~
									No. 10 M&D	~
							Brown Stock Unit 3	~	No. 5&6 Hardstock	~
									No. 7 Hardstock	~
Multiple Effect Evaporator System	5	ppmv @ 10% O_2	5	ppmv @ 10% O_2	NE		NE		NE	
Condensate Stripper System	5	ppmv @ 10% O_2	5	ppmv @ 10% O_2	NE		NE		NE	
Recovery Boiler (low odour boiler)	5	ppmv @ 8% O_2	5	ppmv @ 8% O_2	Recovery Boiler Stack	1 *	New Recovery Boiler	0.34 *	Recovery Boiler	9 *
Recovery Boiler (with direct contact evaporator)	-	ppmv @ 8% O_2	20	ppmv @ 8% O_2	NE		Old Recovery Boiler	19 *	NE	
Lime Kiln	8	ppmv @ 10% O_2	20	ppmv @ 10% O_2	Lime Kiln Scrubber Stack	8 *	Lime Kiln with ESP	8 *	Lime Kiln	44 *
Smelt Dissolving Tank	8.4	mg/kg BLS	8.4	mg/kg BLS	Smelt Dissolving Tank	17 ^	Smelt Dissolving Tank	29 ^	Smelt Dissolving Tank with Concentrator	94 ^
									Smelt Dissolving Tank without Concentrator	38 ^

BLS - Black Liquor Solids
NE - no emissions

*TRS concentration at reference O_2 concentration calculation:

$$C_{(\text{reference } O_2\%)} = C_{(\text{actual } O_2\%)} * (20.9 - \text{reference } O_2\%) / (20.9 - \text{actual } O_2\%)$$

^Converted based on 0.66 kg pulp/kg BLS

~These are existing facilities, therefore there is no emission standard specified by the U.S.EPA at this time

A foul condensate stripping system was started-up in March 1995. This should reduce emissions from plant effluent (at the effluent pump house), and in any process where these condensates are re-used.

Recovery Boiler

The concentrated black liquor (65%) is fired through 2 guns into the Babcock and Wilcox low odour recovery boiler at approximately 0.8 m^3/min. Sodium sulphate is utilized as a make-up chemical.

The off gas is vented through two electrostatic precipitators and is released from a 75 m stack. The TRS emission rate is approximately 0.16 g/s with a stack concentration below the NSPS (Table 3.9).

The NCG emergency vent is through the Recovery Stack for greater dispersion. An application for a Certificate of Approval was submitted in 1993 for emergency venting of the condensate stripper system through the recovery stack when the lime kiln is not operational.

Smelt Dissolving Tank

Smelt from the recovery boiler flows to the smelt dissolving tank where weak wash is added to make green liquor. The smelt is treated in recausticizers and green and white liquor processing equipment. The resultant white liquor is stored and reused in a digester as cooking liquor. The emissions from the smelt dissolving tank are vented through a scrubber/demister system for particle removal. The dissolving tank scrubber uses water as a scrubbing liquor which is discharged to the sewer after use. TRS is emitted from the scrubber at a rate of approximately 0.16 g/s. The stack concentration is approximately twice the NSPS (Table 3.9). Use of caustic for the scrubbing liquid should lower the concentration enough to meet the NSPS. The TRS emissions could be reduced somewhat by using weak wash for scrubbing, instead of water, but a greater improvement would be obtained with caustic.

Lime Kiln Scrubber

Green liquor from the recovery boiler is sent to 4 recausticizers which produce lime mud and white liquor. The lime mud is thickened and washed prior to being fed to the lime kiln to regenerate lime. Excess filtrate is recycled back to the mud washer and, when required, fresh water is used as wash water. The white liquor produced is stored and reused in the digesters as cooking liquor.

NCGs from the evaporator, digester and turpentine systems are incinerated in the lime kiln. The combustion gases are drawn through a venturi scrubber and inertial separator, prior to exhausting to the atmosphere. The lime kiln scrubber uses recycled scrubber filtrate as a scrubbing liquor. Fresh water is used for scrubber make-up.

TRS emissions from the lime kiln are reported to be 0.096 g/s. The stack TRS concentration corrected to 10% O_2 was approximately 8 ppmv, just at the NSPS.

Tall Oil Scrubber

Insoluble sodium soaps skimmed off from the black liquor evaporator stage are reprocessed in the tall oil plant. The soaps are converted to raw tall oil using acid and a water wash. The off gasses from this process are vented through a packed bed scrubber which uses NaOH as a scrubbing liquor for TRS control. The scrubbing liquor is discharged to the sewer when spent. Emissions from the tall oil plant are reported to be 0.005 g/s.

Effluent Pump House Vent

TRS emissions from this source are quite high (0.075 g/s) with a stack concentration of 1,207 ppmv. This high concentration is in a low volume sewer vent flow. Rainy River has recognized this as a significant source. A caustic scrubber is currently planned for installation on the effluent pump house for the control of TRS from this source. In addition, the installation of a foul condensate stripper to reduce the TRS in process condensates will also reduce emissions from this source.

The emissions from the tall oil plant and effluent pump house are quite variable. The emissions from the smelt dissolving tank have decreased over the years. They were 85 ppm in 1989, 17 ppm in 1991, 23 ppm in 1993 and 9.1 ppm in 1994. The reason for this decrease is not clear.

3.4.2 Malette - Smooth Rock Falls

The Malette Pulp mill is located in Smooth Rock Falls. It produces approximately 411 ADt pulp/day. Malette is required to conduct stack testing as part of the conditions of their Certificate of Approval. There are several stack testing reports prepared by IMET and some O.Reg. 346 air dispersion modelling results. The emissions listed in the stack testing reports are highly variable and there appear to be inconsistencies in the emission rate calculations. In addition, the MOEE has determined that the stack testing methodology used may not meet their protocol. The data presented here (Table 3.7) was extracted from the IMET reports of June 1992, January 1993, August 1993 and the Concord report of February 1993.

Lime Kiln

The lime kiln recovers lime from calcium carbonate produced in the recausticizing process. The lime kiln is also used to incinerate methanol from the condensate stripper and foul NCGs in the presence of excess air (NCGs are vented to the atmosphere in an emergency). TRS compounds in the NCG stream combusted and produce CO_2 and SO_2. The hot combustion gases travel counter-current to the lime mud flow, which contains residual NaOH, Na_2S and Na_2CO_3. Some of the SO_2 in the gas stream reacts with these residuals. Prior to 1993, the exhaust gases from the lime kiln were treated in a wet venturi scrubber (using weak wash as the scrubbing liquid) before venting to atmosphere. After 1993, the wet scrubber was replaced with a high efficiency electrostatic precipitator (ESP) for particulate control.

Before 1993, when the wet scrubber was used, emissions of TRS from the lime kiln were approximately 1 g/s. These high emissions were likely due to the use of weak wash on the scrubber. The use of weak wash on a lime kiln is not recommended as the CO_2 in the flue gas will liberate the H_2S from the sodium sulphide (Na_2S) in the weak wash. Since 1993, TRS emissions have approximately 0.05 g/s with an ESP (Table 3.7). The emissions are at the U.S. EPA NSPS of 8 ppmv (corrected to 10% O_2) (Table 3.9). With a scrubber, the under flow is added to the mud before the lime mud precoat filters, which is ahead of the kiln. With an ESP,

the collected dust is added directly to the kiln feed, thereby taking 10 to 30% of the mud loading off the precoat filter. With a lower loading, the performance of the precoat filter improves, resulting in dryer lime (with less Na_2S) and more oxidation of the Na_2S left in the mud. These factors would result in lower kiln TRS emissions but the main impact is likely the elimination of contact of weak wash with kiln flue gas (Blackwell 1994).

Smelt Dissolving Tank

Smelt from the recovery boiler flows into the dissolving tank, where the smelt is dissolved in weak wash to form green liquor. The exhaust gases are vented through a venturi scrubber to remove particulate before venting. The scrubbing liquid is water. The smelt dissolving tank has a 6 foot demister located within the stack. It is combined with a set of spray nozzles which fire at intervals through the hour to remove particulate material. The emissions from the smelt dissolving tank (0.21 g/s TRS) are approximately twice the U.S. EPA NSPS (Table 3.9) and is considered high by industry standards. Use of caustic in the scrubber should reduce the emissions considerably.

Old Recovery Boiler

This 105 U.S. gpm. Babcock and Wilcox recovery boiler built in 1965 has a direct contact cyclone evaporator. Black liquor from the brownstock washing is concentrated from 15% solids in a series of rising film evaporators to strong black liquor and is stored in one of three storage tanks. The foul condensate is steam stripped. Liquor for the storage tanks is pumped through the electrostatic precipitators hopper to collect the particulate removed from the flue gases. The liquor is then sent to the cyclone evaporator to pick up additional particulate removed from the flue gases. Emission control equipment consists of an electrostatic precipitator, followed by a Teller Environmental cross-flow heat recovery scrubber. This is a packed-bed scrubber using weak wash as scrubbing liquid, designed for partial removal of TRS and heat recovery. The emissions are then directed through the stack to the atmosphere.

This recovery boiler has a direct-contact concentrator and no black liquor oxidation system. The emissions from this source (1.56 g/s TRS) are approximately 4 times higher (23 ppm) compared to the NSPS of 5 ppmv (corrected to 8% O_2) but is achieving the practical limit for an older boiler (Table 3.9). Parts of this recovery boiler have been rebuilt (i.e. the economizer section and

some retubing). A black liquor oxidation system may be more effective than a packed-bed scrubber for control, especially since these scrubbers are susceptible to channelling and plugging. A black liquor oxidation system could also improve the operation of the recovery boiler. Depending on the age of the boiler and its expected life, the foregoing suggestion may not be the best solution, especially considering that a minimal emission reduction if any would be achieved. More details on the system are necessary to evaluate the feasibility of this option. A consultant has been retained by Malette to assess Recovery Boiler #1.

Recovery Boiler #2

This is a low odour Babcock and Wilcox recovery boiler installed in 1991. It has a capacity of 105 U.S. gpm. and the exhaust is vented through a two-chamber ESP. The boiler was installed to increase production and to decrease the load on the old recovery boiler. The flue-gas from the recovery boiler is scrubbed with weak wash in a dynamic scrubber. The foul condensate is steam stripped prior to use. The emissions from this boiler (0.016 g/s TRS) are well below the NSPS (Table 3.9).

Brownstock Washers

This is a three-stage washing process enclosed in a hood system which vents through two stacks. There are no emission controls. Filtrate from O_2 delignification and fresh hot water are used to wash brownstock pulp.

3.4.3 Domtar Packaging - Red Rock

Construction began on this facility in 1936 with production beginning in 1942. Over the years, there have been several changes in ownership of this facility and many changes to the process. The plant produced bleached kraft pulp which was used internally to manufacture linerboard and newsprint. In 1992, the production of newsprint ceased and the bleach plant was closed, leaving only unbleached kraft pulp production.

The Domtar Packaging Red Rock Mill currently produces approximately 840 ADt/day of pulp. The mill utilizes both hardwood and softwood. A TRS emissions inventory was prepared, as required in an MOEE control order issued on 29 September 1986. The data presented in this

report (see Table 3.8) was extracted from a report entitled *Domtar Packaging Red Rock Mill 1988 TRS Emission Inventory* dated December 1988.

Digesters

There is one continuous digester and eleven batch digesters at this site. The relief gases from the batch digesters are processed in a turpentine recovery system. The blow gases from all of the digesters are condensed for heat recovery. The residual gases are burned in the lime kiln.

Brownstock Washers

There are two brownstock washer lines (hardstock line and M&D line) which utilize kraft mill condensates as wash water to separate the black liquor from the pulp. These lines process both hardwood and softwood. The M&D line is a fine chip line. Each of the brownstock washer lines consist of multiple vacuum drum counter-current flow washers. New *Beloit* three-stage pressure washers were installed in 1989. The old hardstock washer line is used only as backup for the *Beloit* washer line. There are hoods that extend over and around the drums which exhaust via fans directly to the atmosphere without controls. The black liquor washed from the pulp is stored in filtrate tanks. Air drawn through the pulp mats into the filtrate tanks is vented on each washer line by a foam tank vent. The oxygen content of this source was not provided but is probably about 21% and is therefore adequate for use as incinerator combustion air.

In the first quarter of 1995 the brownstock washing configuration will change. The *Beloit* three stage pressure washers will continue to process hardstock. The pressure washers use only kraft mill condensates as wash water. The fine chip (short fibre pulp) currently being run on the M&D line will be washed on the old hardstock 3 stage vacuum washer lines (drums No. 6, 7 and 8).

In the event of problems with the pressure washer system, hardstock will be washed on the old hardstock vacuum washers and the short fibre pulp will be washed on the M&D vacuum washer line. The pressure washers are not vented. TRS remains with the washed stock until released in the pulp high density storage tanks or at the paper machines when the pH drops.

To properly consider TRS emissions and the cost of compliance with lower regulatory standards, both of these operational situations need to be evaluated as the mill will be required to meet the standard regardless of which configuration is used.

Causticizing

Lime (from the lime kiln) is added to clarified green liquor to form white liquor (cooking liquor). Emissions from the green liquor clarifier (0.0006 g/s TRS) and recausticizers (0.0003 and 0.0015 g/s TRS) are vented directly to the atmosphere. There are no add-on controls for these emission points.

Lime Mud Washing

The lime mud is separated from the white liquor by settling. The lime mud is washed with clean hot water (65°C) and de-watered before being recalcined in the lime kiln. The final dewatering is carried out on the lime mud drum filter which is served by a hood vent and fan which exhausts directly to the atmosphere. The TRS emissions from the lime mud filter hood vent are reported to be 0.0009 g/s with a stack concentration of 0.6 ppmv.

Lime Kiln

Lime mud from the causticizing area is converted to calcium oxide in the lime kiln. Particulate is controlled with a variable throat, high pressure drop venturi scrubber using fresh water and recirculated lime dust slurry as the scrubbing medium.

The TRS emissions from the lime kiln are high (0.74 g/s) (44 ppmv corrected to 10% O_2), approximately twice the U.S.EPA existing mill emission guideline (Table 3.9). This may be a result of poor lime mud washing and/or poor performance of the lime mud precoat filter. This would result in an increased loading of Na_2S to the lime kiln producing increased TRS emissions.

The design capacity of the lime kiln is 220 ton/day CaO (9.2 MBtu/ton) and it is currently running at 190 ton/day CaO.

Condensate Stripper

Condensates from the digester blow gas, the turpentine recovery system and the evaporator vacuum systems are steam stripped prior to reuse as wash water in brownstock washing. The steam stripper was recently upgraded - the pall rings were first changed to berl saddles and were in turn replaced with a solid packing material - to increase capacity and effectiveness. The stripped gases are conveyed to the lime kiln for incineration.

Black Liquor Recovery

Black liquor from the brownstock washing step is concentrated in two parallel multiple-effect evaporator sets, and subsequently, a three-body concentrator to a solids content suitable for combustion in the recovery boiler. The NCGs from the evaporators are collected and routed to the lime kiln for combustion. Should the NCG line to the lime kiln become plugged, NCGs are vented through the smelt dissolving tank scrubber vent.

Recovery Furnace

The recovery furnace is a Combustion Engineering "low odour design" furnace. The emissions are normally vented from a 250 ft. high stack. The stack collapsed in 1988 due to corrosion from chloride ions and was rebuilt in 1989 to its original height.

The recovery furnace is the largest contributor to the mass emissions (0.67 g/s TRS) and has a stack concentration of 9 ppmv (corrected to 8% O_2 - U.S.EPA reference level), 80% greater than the NSPS and the existing mill guidelines. This could probably be reduced with improved operational practices such as those discussed in Section 3.2.7. Process control variables which can affect the TRS emission rate include availability of sufficient excess oxygen in the furnace, gas turbulence, rate of solid feed, spray pattern and droplet size.

The design capacity of the recovery boiler is 2,400,000 lb. dry solid/d producing 400,000 lb./h steam.

Smelt Dissolving Tank

Steam from the smelt dissolving tank and entrained air are exhausted to the atmosphere via the smelt dissolving tank vent. Particulate control for this vent is provided by a *UOP-Turbulaire* (venturi) scrubber utilizing weak wash as the scrubbing liquor. The mill has the capability to switch to clean hot water, however this would result in less fresh water use for mud washing and impact the mud washing efficiency.

If the NCG line to the lime kiln becomes plugged, Domtar vents the concentrator seal tank to the inlet of the dissolving tank scrubber. This is shown on Table 3.8 as smelt dissolving tank - with concentrator (1.37 g/s TRS). The normal operation is without the concentrator NCGs (0.56 g/s TRS).

The smelt dissolving tank is one of the largest contributors to the total mass emission of TRS from this facility. The emissions seem to be high. Switching to caustic could reduce the emissions from this source.

Effluent Lagoon

Domtar is bringing a secondary treatment lagoon on line in 1995 which will be another potential release point for TRS, under anaerobic conditions. As long as the effluent is sufficiently free of reduced sulphur compounds when it enters the lagoon, and the lagoon is maintained under aerobic conditions, TRS emissions should not be released from this potential source. No direct information on this system will be available until the system is operational. The potential problems and associated costs cannot be accurately assessed.

3.5 Generic Costs of TRS Control Options

This section describes generic costs of TRS control options. Table 3.10 presents the reported capital costs, discussed in the following sections, for controls on various sources. Table 3.11 gives the reported annualized costs for the different control options. The annualized cost reflects both the operating and maintenance costs and the capital cost distributed on a yearly basis over 10 years. Details on the assumptions made to calculate the annualized costs can be found in U.S. EPA 1979 and U.S.EPA 1993a. These costs are compiled from data collected from kraft pulp

mills in the United States and Canada. In the following discussion, the CO # represents the Control Option number as shown in Tables 3.10 and 3.11. Capital costs reported by Blackwell (1994) are considered to be accurate within -25% to +75%.

3.5.1 Recovery Boiler

The physical life of a boiler is 20 to 30 years. Units are available in sizes ranging from about 200 air dried tonnes of pulp per day (ADt/d) to 1,500 ADt/d. The use of a low odour recovery boiler is technically feasible in any of Ontario's kraft mills. The capital cost for conversion of older boilers (with direct-contact evaporator) to low odour design is in the order of $35,000,000 (Blackwell 1994) (CO #6); this includes additional liquor evaporation capacity. Conversion of an old boiler design to low odour design can take many weeks.

H.A. Simons et al. 1994 estimated the capital cost (order of magnitude) of a low odour conversion at 30 to 40 million dollars (CO #6) for a 1,500 tBLS/day boiler (a typical size for a 750 ADt/d pulp mill or $45,000/GJ per hour heat input). This estimate is based on the extensive structural work required, and the 3 to 4 week down time. Modern conversions will result in a reduction in SO_2 and VOC emissions as well. A low odour conversion will result in an increase in boiler efficiency and steam generation, and a reduction in precipitator corrosion.

U.S. EPA 1979 states that based on the information gathered from 17 mills, the capital cost data for recovery furnaces correlated reasonably well with mill size. This document gives estimated retrofit costs (capital and annualized) for furnace replacement and installation of second-stage black liquor oxidation for different size pulp mills.

Retrofit costs (capital and annualized) for recovery furnaces older than 1955 are assumed to include replacement of the furnace plus a complete two-stage black liquor oxidation system. Though replacement of the old furnace with a low-odour furnace, is probably the best option.

The recovery boiler provides a possible incineration point for lean gas containing TRS collected in the mill, although operators may resist this application. Domtar (1995) states that in furnaces which have tried to burn such gases, corrosion has occurred in the wind boxes. It has also resulted in unacceptable workplace TRS levels associated with leaks of combustion air from the air ducts as the furnaces use the forced draft air supply. These concerns can be addressed

Table 3.10

Reported Capital Costs for Pulp Mill Control Equipment

Control Option	Estimated Control Efficiency	Reported Capital Cost ($) Mill Size (ADT/d) 500	1000	1500	$US Year	Source	Notes
1. Combustion of emissions from brown stock foam tank, weak black liquor tank	94%	$170,000	$280,000	$410,000	1988	U.S.EPA 1993a	
2. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in recovery boiler	94%	$1,000,000	$1,600,000	$2,100,000	1988	U.S.EPA 1993a	
	94%		$3,000,000		1994(Can)	Blackwell 1994	
	94%	$900,000	$1,500,000	$1,900,000	1976	U.S.EPA 1979	
	94%		$4,000,000		1990 (Can)	Rainy River 1994	6
3. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in a separate incinerator	94%	$1,600,000	$2,500,000	$3,200,000	1976	U.S.EPA 1979	
	94%		$6,000,000		1994(Can)	Blackwell 1994	11
4. Collection of emissions from brown stock washers and vent from boiler stack	0%		$1,000,000		1994 (Can)	Blackwell 1994	
5. Steam stripping of pulping wastewater followed by incineration in existing device	94%	$1,620,000	$3,500,000	$4,600,000	1988	U.S.EPA 1993a (combined)	9
	94%	$1,157,000	$2,500,000	$3,286,000	1988	U.S.EPA 1993a (int)	7
	94%	$2,638,000	$5,700,000	$7,491,000	1988	U.S.EPA 1993a(non-int)	8
	94%		$5,000,000		1994(Can)	Blackwell 1994	
	94%		$5,200,000		1990 (Can)	Rainy River 1994	
6. Coversion to low odour recovery boiler	75%	$13,400,000	$23,300,000	$32,200,000	1976	U.S.EPA 1979	
	75%		$35,000,000		1994(Can)	Blackwell 1994	
	75%		$35,000,000		1994(Can)	H.A.Simons 1994	
7. Black liquor oxidation system (emissions from recovery furnace)	99%	$600,000	$1,000,000	$1,500,000	1976	U.S.EPA 1979	
	99%		$2,000,000		1994(Can)	Blackwell 1994	
8. Control of emissions from black liquor oxidation vents	80-94%	$220,000	$330,000	$432,000	1976	U.S.EPA 1979	1
	80-94%	$400,000	$560,000	$700,000	1976	U.S.EPA 1979	2
	100%	$1,080,000	$1,640,000	$2,100,000	1976	U.S.EPA 1979	3
	80-94%		$1,000,000		1994(Can)	Blackwell 1994	3,10
9. Collection of batch digester/evaporator vent gases and incineration in lime kiln	94%	$400,000	$900,000	$1,600,000	1976	U.S.EPA 1979	4
	94%	$900,000	$2,000,000	$3,500,000	1976	U.S.EPA 1979	5
	94%		$2,000,000		1994(Can)	Blackwell 1994	
	94%		$4,500,000		1990(Can)	Rainy River 1994	
10. Collection of continuous digester vent gases and incineration	94%	$300,000	$400,000	$500,000	1976	U.S.EPA 1979	
	94%		$2,000,000		1994(Can)	Blackwell 1994	
11. Lime kiln process control package	80-94%	$75,000	$100,000	$200,000	1976	U.S.EPA 1979	
			$500,000			Blackwell 1994	
12. Lime mud washing capacity *		$480,000	$730,000	$950,000	1976	U.S.EPA 1979	4
		$960,000	$1,460,000	$1,900,000	1976	U.S.EPA 1979	5
13. Lime mud recycle			$50,000		1994(Can)	Blackwell 1994	
14. Large lime mud precoat filter *			$3,000,000		1994(Can)	Blackwell 1994	
15. Incineration of condensate stripper emissions in existing combustion device	94%	$16,200	$22,700	$28,100	1976	U.S.EPA 1979	
			$400,000		1994(Can)	Blackwell 1994	
16. Switch from weak wash to caustic on the smelt dissolving tank scrubber	75%		$200,000		1994(Can)	Blackwell 1994	

Table 3.10

Reported Capital Costs for Pulp Mill Control Equipment

Control Option	Estimated Control Efficiency	Reported Capital Cost ($) Mill Size (ADT/d) 500	1000	1500	$US Year	Source	Notes
17. Small scrubber (sewer vent gas)	50-90%		$300,000		1994(Can)	Blackwell 1994	
Small scrubber (clarifier vents, turpentine decanter vent)	75%		$500,000		1994(Can)	Blackwell 1994	
18. Large scrubber (BSW hood vents etc)	50%		$3,000,000		1994(Can)	Blackwell 1994	
Large scrubber (black liquor tanks)	75%		$1,000,000		1994(Can)	Blackwell 1994	
19. Recovery boiler scrubber	90%		$10,000,000		1994(Can)	Blackwell 1994	
	90%		$7,800,000		1994(Can)	H.A.Simons 1994	
20. New smelt dissolving tank vent scrubber	75%		$1,600,000		1990 (Can)	Rainy River 1994	
21. Lime kiln stack venturi scrubber	80%		$4,000,000		1990 (Can)	Rainy River 1994	
22. Bleach plant stack scrubber	50%-90%		$2,500,000		1990 (Can)	Rainy River 1994	
23. Tall oil plant vent scrubber	90%		$400,000		1990 (Can)	Rainy River 1994	
24. Effluent building vent scrubber	50%-90%		$400,000		1990 (Can)	Rainy River 1994	
25. New Lime Kiln	80%		$3,000,000		1976	U.S.EPA 1979	
			$30,000,000		1994(Can)	Blackwell 1994	
26. New Diffusion Brown Stock Washers	99%		$20,000,000		1994(Can)	Blackwell 1994	

ADT/d - air dried tons/day

Notes:

1 Black liquor vent gases incinerated in recovery boiler
2 Black liquor vent gases incinerated in separate incinerator
3 Black liquor oxidation with molecular oxygen
4 Low retrofit penalty
5 High retrofit penalty
6 The combustion source is not clear - this may be a separate incinerator
7 Integrated with evaporator set
8 Not integrated with evaporator set
9 Based on a weighted average of and integrated and non-integrated evaporator set
10 switching to oxygen instead of air
11 $5,000,000 for incinerator and $1,000,000 for ducting

[a] same technology
Incineration 94% reduction of TRS (U.S.EPA 1993a)
Black liquor oxidation can offer 99% (Springer 1986)
U.S.EPA 1979 reports incineration of emissions from black liquor oxidations systems 80% efficient
Scrubber efficiency 80% with weak wash; using a packed bed section up to 95% (H.A.Simons 1994)
Improving lime mud washing and introducing process control have reported emission reductions of more than 80%
U.S.EPA 1979 reports 75% reduction for process controls; 94% for process controls and high efficiency mud washing
Caustic scrubbing can have removal efficiencies of 50-90% - see page 3-14 text (Blackwell 1994)
Condensate stripping - removal efficiencies of up to 94% reported (U.S.EPA 1993a) and subsequent incineration (94%) overall reduction 94.4%
Conversion to low odour boiler from black liquor oxidation (20 ppm - 5 ppm) (75%) (Blackwell 1994)
Switch from weak wash to caustic (20 ppm to 5 ppm) 75% (Blackwell 1994)
Molecular oxidation of black liquor has no vent points - closed system - 100% (U.S.EPA 1979)

Capital Cost estimate from Rainy River was assumed to be in 1990 $Can.

Table 3.11

Reported Annualized Costs for Pulp Mill Control Equipment

Control Option	Estimated Control Efficiency	Reported Annualized Cost ($/year) Mill Size (ADT/d) 500	1000	1500	$US Year	Source	Notes
1. Combustion of emissions from brown stock foam tank, weak black liquor tank	94%	$58,000	$83,000	$110,000	1988	U.S.EPA 1993a	
2. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in recovery boiler	94%	$210,000	$350,000	$450,000	1988	U.S.EPA 1993a	
	94%		-		1994(Can)	Blackwell 1994	
	94%	$192,000	$326,000	$423,000	1976	U.S.EPA 1979	
	94%		-		1990 (Can)	Rainy River 1994	6
3. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in a separate incinerator	94%	$900,000	$1,670,000	$2,400,000	1976	U.S.EPA 1979	
	94%		-		1994(Can)	Blackwell 1994	11
4. Collection of emissions from brown stock washers and vent from boiler stack	0%		-		1994 (Can)	Blackwell 1994	
5. Steam stripping of pulping wastewater followed by incineration in existing device	94%	$840,000	$1,900,000	$2,300,000	1988	U.S.EPA 1993a (combined)	9
	94%	-	-	-	1988	U.S.EPA 1993a (int)	7
	94%	-	-	-	1988	U.S.EPA 1993a(non-int)	8
	94%		-		1994(Can)	Blackwell 1994	
	94%		-		1990 (Can)	Rainy River 1994	
6. Coversion to low odour recovery boiler	75%	$2,270,000	$4,000,000	$5,470,000	1976	U.S.EPA 1979	
	75%		-		1994(Can)	Blackwell 1994	
	75%		-		1994(Can)	H.A.Simons 1994	
7. Black liquor oxidation system (emissions from recovery furnace)	99%	$153,000	$242,000	$360,000	1976	U.S.EPA 1979	
	99%		-		1994(Can)	Blackwell 1994	
8. Control of emissions from black liquor oxidation vents	80-94%	$60,000	$96,000	$133,000	1976	U.S.EPA 1979	1
	80-94%	$233,000	$420,000	$605,000	1976	U.S.EPA 1979	2
	100%	$309,000	$509,000	$645,000	1976	U.S.EPA 1979	3
	80-94%		-		1994(Can)	Blackwell 1994	3,10
9. Collection of batch digester/evaporator vent gases and incineration in lime kiln	94%	$96,000	$210,000	$360,000	1976	U.S.EPA 1979	4
	94%	$207,000	$425,000	$773,000	1976	U.S.EPA 1979	5
	94%		-		1994(Can)	Blackwell 1994	
	94%		-		1990(Can)	Rainy River 1994	
10. Collection of continuous digester vent gases and incineration	94%	$67,000	$96,000	$125,000	1976	U.S.EPA 1979	
	94%		-		1994(Can)	Blackwell 1994	
11. Lime kiln process control package	80-94%	$54,000	$107,000	$175,000	1976	U.S.EPA 1979	
			-			Blackwell 1994	
12. Lime mud washing capacity [a]		$91,200	$139,000	$181,000	1976	U.S.EPA 1979	4
		$182,000	$278,000	$362,000	1976	U.S.EPA 1979	5
13. Lime mud recycle			-		1994(Can)	Blackwell 1994	
14. Large lime mud precoat filter [a]			-		1994(Can)	Blackwell 1994	
15. Incineration of condensate stripper emissions in existing combustion device	94%	$6,300	$7,800	$8,900	1976	U.S.EPA 1979	
			-		1994(Can)	Blackwell 1994	
16. Switch from weak wash to caustic on the smelt dissolving tank scrubber	75%		-		1994(Can)	Blackwell 1994	

Table 3.11

Reported Annualized Costs for Pulp Mill Control Equipment

Control Option	Estimated Control Efficiency	Reported Annualized Cost ($/year) Mill Size (ADT/d) 500	1000	1500	$US Year	Source	Notes
17. Small scrubber (sewer vent gas)	50-90%		-		1994(Can)	Blackwell 1994	
Small scrubber (clarifier vents, turpentine decanter vent)	75%		-		1994(Can)	Blackwell 1994	
18. Large scrubber (BSW hood vents etc)	50%		-		1994(Can)	Blackwell 1994	
Large scrubber (black liquor tanks)	75%		-		1994(Can)	Blackwell 1994	
19. Recovery boiler scrubber	90%		-		1994(Can)	Blackwell 1994	
	90%		-		1994(Can)	H.A.Simons 1994	
20. New smelt dissolving tank vent scrubber	75%		-		1990 (Can)	Rainy River 1994	
21. Lime kiln stack venturi scrubber	80%		-		1990 (Can)	Rainy River 1994	
22. Bleach plant stack scrubber	50%-90%		-		1990 (Can)	Rainy River 1994	
23. Tall oil plant vent scrubber	90%		-		1990 (Can)	Rainy River 1994	
24. Effluent building vent scrubber	50%-90%		-		1990 (Can)	Rainy River 1994	
25. New Lime Kiln	80%		-		1976	U.S.EPA 1979	
			-		1994(Can)	Blackwell 1994	
26. New Diffusion Brown Stock Washers	99%		-		1994(Can)	Blackwell 1994	

ADT/d - air dried tons/day

Notes:

1 Black liquor vent gases incinerated in recovery boiler
2 Black liquor vent gases incinerated in separate incinerator
3 Black liquor oxidation with molecular oxygen
4 Low retrofit penalty
5 High retrofit penalty
6 The combustion source is not clear - this may be a separate incinerator
7 Integrated with evaporator set
8 Not integrated with evaporator set
9 Based on a weighted average of and integrated and non-integrated evaporator set
10 switching to oxygen instead of air

[a] same technology
Incineration 94% reduction of TRS (U.S.EPA 1993a)
Black liquor oxidation can offer 99% (Springer 1986)
U.S.EPA 1979 reports incineration of emissions from black liquor oxidations systems 80% efficient
Scrubber efficiency 80% with weak wash; using a packed bed section up to 95% (H.A.Simons 1994)
Improving lime mud washing and introducing process control have reported emission reductions of more than 80%
U.S.EPA 1979 reports 75% reduction for process controls; 94% for process controls and high efficiency mud washing
Caustic scrubbing can have removal efficiencies of 50-90% - see page 3-14 text (Blackwell 1994)
Condensate stripping - removal efficiencies of up to 94% reported (U.S.EPA 1993a) and subsequent incineration (94%) overall reduction 94.4%
Conversion to low odour boiler from black liquor oxidation (20 ppm - 5 ppm) (75%) (Blackwell 1994)
Switch from weak wash to caustic (20 ppm to 5 ppm) 75% (Blackwell 1994)
Molecular oxidation of black liquor has no vent points - closed system - 100% (U.S.EPA 1979)

Capital Cost estimate from Rainy River was assumed to be in 1990 $Can.

through proper design and operation, but to be safe, concentrated non-condensible gases and gases with a high water vapour content should be avoided.

Boiler suppliers and contacts are given in Appendix A.

3.5.2 Black Liquor Oxidation

Black liquor oxidation is a proven technology. It is considered to be reliable, with little down time. It can improve the performance of a recovery boiler in recovering chemicals. The service life of the equipment is approximately 20 years. It is available in any size, and the size does not affect the efficiency of oxidation. There are no legal or licensing considerations with this process. It is compatible with improved air mixing in the recovery boiler for overall reduction in boiler stack TRS. The capital cost of a black liquor oxidation system will be in the order of $2,000,000 (Blackwell 1994) (CO #7).

Black liquor oxidation can be applied using oxygen instead of air. The capital cost is in the $1,000,000 range (CO #8)with an operating cost for buying the oxygen of around $200,000 per year.

U.S. EPA 1979 describes the system representative of the best technology:

1) two-stage oxidation;
2) retention time of five hours for both stages combined;
3) stand-by blower capacity; and
4) monitoring of both oxidizing air and liquor flow rates.

Capital costs for black liquor oxidation systems do not correlate well with mill size (U.S. EPA 1979) (CO #7). This is likely because mill operations and mill layout vary considerably, resulting in highly site-specific retrofit costs.

Historically, black liquor oxidation vents have been discharged directly to the atmosphere. U.S. EPA 1979 gives estimated capital and annualized costs to destroy vent emissions in a recovery furnace, in a separate incinerator and for treatment with molecular oxygen. These estimates were based on the following assumptions (CO #8):

Separate Incinerator

1) based on a 20,000 scfm incinerator required for a 1,000 ton/day mill;
2) basic cost information was provided by the Industrial Gas Cleaning Institute;
3) capital costs for a 500 ton/day and 1,500 ton/day mill were developed using a scale factor of 0.3;
4) fuel requirements were calculated to be 19 MBtu/hour for the 20,000 scfm incinerator assuming the use of primary and secondary heat recovery; and
5) reflects high retrofit (capital) costs.

Molecular Oxygen In Oxidizer

1) based on 45 tons oxygen/800 ton pulp produced;
2) energy consumption is assumed to be 20 kWh/ton pulp or 380 kWh/ton O_2 produced; and
3) reflects high retrofit (capital) costs.

Incineration in Recovery Boiler

1) reflects minimal retrofit problems. However, Blackwell states that the high moisture content and large flow may make this impractical (Blackwell 1994).

Suppliers of black liquor oxidation systems are given in Appendix A.

3.5.3 Lime Kiln Process Control (CO #11)

As discussed in Section 3.2.10, the lime kiln emissions can be partially controlled by effective process control as well as by lime mud feed with a low sulphide content. To achieve effective lime kiln control, it may be necessary to increase the air flow rate and the temperature of the cold end of the kiln. The estimated capital cost was presented in Table 3.7. If the lime kiln is short on lime burning capacity, it may be necessary to add another lime kiln. According to the U.S. EPA (1979), the capital cost of a new lime kiln is approximately $3 million (U.S.). However, Blackwell (1994) estimates that the capital cost for a new unit including precipitator and new lime mud precoat filter, would be in the order of $30,000,000 (CO #25).

3.5.4 Lime Mud Washing

Improved lime mud washing decreases kiln TRS emissions. Lime mud washing can be improved in several ways:

1) *Maximize the slurry concentrations* in the underflows from the white liquor clarifier (or pressure filter) and the lime mud washer (or pressure filter). This is mainly an operational issue.

2) *Use clean wash water instead of contaminated condensate*, at the last washing point, the lime mud precoat filter. Use of contaminated condensate with 15 ppm TRS will increase kiln TRS emissions concentrations by about 2 ppm.

3) *Increase the temperature of the wash water* on the lime mud precoat filter to about 80°C. This improves the performance of the filter.

4) *Lime Mud Recycle:* Lime mud recycle is a patented technology available from Sandwell Inc. for a $20,000 one-time licence fee. The cost of implementation (capital) is in the $10,000 to $50,000 range (CO #13).

5) *Large Lime Mud Precoat Filter:* A new lime mud filter installation has a capital cost of around $3,000,000 (CO #14, CO #12).

A new lime mud precoat filter requires a 5 to 10 day shut down to tie in with the existing equipment; this can be done as part of a scheduled mill shut down. The other techniques can be implemented during operation. Lime mud precoat filters are available in sizes covering 100 to around 1,500 ADt/d production. Except for the lime mud recycle technique, there are no legal or licensing considerations.

Suppliers of lime mud washing systems are given in Appendix A.

3.5.5 Scrubbers

Scrubbers are not often used to control TRS alone in the pulp and paper industry. Scrubbers are quite often used in some cases to control particulate. Some TRS mitigation may be achieved in these scrubbers. Scrubbers can be designed to control some TRS compounds, specifically H_2S. The removal rate depends on the solubility of the contaminant in the scrubbing liquid.

Any retrofit work to use caustic as a scrubbing medium on the smelt dissolving tank vent could be done as part of a scheduled mill shut down. There are no legal or licensing considerations in using caustic in dissolving tank vent scrubbers. Other pollutants, such as particulate, are not impacted in switching from weak wash to caustic. The switch is compatible with other TRS emission control systems in the mill. The capital cost for switching from weak wash to caustic make-up on the smelt dissolving tank vent would be in the $200,000 range (Blackwell 1994) (CO #16) with annual chemical costs in the order of $100,000/year. It should be technically feasible at most Ontario kraft mills.

Smelt dissolving tank scrubber suppliers are given in Appendix A.

Scrubbers have been used in Canadian kraft mills in various applications for many years. The capital cost for a small scrubber would range from $300,000 (CO #17) (Blackwell 1994) for sewer vent gas to $500,000 for clarifier vents and turpentine vents. The costs for large scrubbers range from $1,000,000 for black liquor tanks to $3,000,000 (CO #18) (Blackwell 1994) for brownstock washer hood vent gases, combined with other gases.

Rainy River 1990 reports the following capital costs for scrubbers at their facility:

New smelt dissolving tank scrubber (CO #20)	$1,600,000
Lime kiln stack venturi scrubber (CO #21)	$4,000,000
Bleach plant stack scrubber (CO #22)	$2,500,000
Tall oil plant vent scrubber (CO #23)	$ 400,000
Effluent building vent scrubber (CO #24)	$ 400,000

Recovery boiler flue-gas scrubbers are reliable, with little down-time outside of normal scheduled mill outages. The time required for engineering, manufacturing and installation is about

12 months, but there is no impact on mill production because tie-ins can be made as part of scheduled mill shut downs. The scrubber shell can last for about 20 years, but the packing may have to be replaced every two years. Recovery boiler scrubbers come in a full range of sizes. There are minimal legal and licensing considerations. The scrubbers also remove most of the SO_2. These scrubbers are feasible for any of the Ontario kraft mills. However, they are an expensive solution. For a 700 ADt/d mill, the total installed capital cost of a recovery boiler flue-gas scrubber would be around $10,000,000 (CO #19)(Blackwell 1994). It is more cost effective to correct the problem at the source, through good black liquor oxidation on older boilers, and improved gas mixing by combustion air system improvements, on all boilers.

H.A. Simons et al. 1994 reports on two scrubbers to be applied to the recovery boiler. The Modo wet scrubber is designed to remove particulate, SO_2 and TRS. It has a heat recovery section and produces fairly clean water. This scrubber has a particular application with the direct-contact evaporator type recovery boiler. Removal rates are approximately 98% for particulate, and 80 to 90% (using a calcium based solution) or 90 to 95% (with caustic) for SO_2. TRS is removed using activated carbon. The total installed capital cost (order of magnitude) is:

$$\text{Total installed cost} = \$525{,}000 \times (\text{flue gas volume in } m^3/s)^{0.51}$$

Therefore, the capital cost would be approximately $7.8 M for a 1670 tBLS/day boiler (CO #19).

The other reported scrubber is the "Teller" which is a venturi/cross-flow type scrubber. It is designed to remove large particles and uses alkaline absorption to remove TRS. A TRS removal efficiency of 80% has been reported. The estimated capital cost (order of magnitude) is approximately $7M in 1994 for a 750 ADt/d hardwood mill. (CO #19)

In general caustic scrubbing is the preferred treatment for TRS from the smelt dissolving tank vent, but not for other emission sources. For other sources, scrubbing is recommended only in special circumstances, when incineration is not practical.

3.5.6 Brownstock Washers

Brownstock washers (displacement type) are a source of fugitive TRS emissions. In most cases, these sources are uncontrolled. It is possible to install a scrubber to treat the vent gases, though this would be a large expense (CO #26, Table 3.10). The best means for controlling this source is generally considered to be collection and conveyance to an on-site incineration device (recovery boiler, power boiler) or to a stand alone incinerator. It is also possible to vent these collected gases to a tall stack such as the recovery boiler stack for greater dispersion. The capital cost is approximately $1,000,000 (Blackwell 1994) (CO #4). Section 3.5.7 describes these options in more detail.

Alternatively, the displacement washers could be replaced with diffusion type washers (as described in Section 3.2.2). Blackwell (1994) estimates the capital cost of replacing a whole brownstock washing line (4 drum washers) to be approximately $20,000,000 (CO #26).

3.5.7 Ductwork and Enclosures Costs

Ductwork is used to convey the collected emissions from the source to the point of control. Several sources may be combined into a single duct routed to the control device. The pulp washers, the knotters and the screens/deckers need an enclosure or hood to capture the emissions. An enclosure is preferred because the capture efficiency is higher and the amount of air collected is reduced by approximately 34% (U.S. EPA 1993a). For this assessment, full enclosures were assumed for costing purposes.

Capital and annualized costs for enclosing systems were developed by the U.S. EPA (BID 1993) based on quotes by suppliers for enclosures installed on pulp washers. These quotes were determined for fibre reinforced plastic (FRP) enclosures with equipment access panels for a typical 1,000 ton per day mill. The capital cost of a single enclosure was estimated at $40,000 U.S. (1991) dollars. For a rotary vacuum pulp washer line that consisted of three rotary vacuum washer drums, three enclosures were required plus two additional support kits at $12,000 U.S. each. A single enclosure was assumed for each of the screens, knotters and deckers. Larger capacity mills were assumed to have multiple lines or units and required additional enclosures. The total capital investment of an enclosure for each screen, knotter and decker was estimated to be $64,000 U.S. Direct and indirect installation costs were assumed to be 50% of the

purchased equipment costs (U.S.EPA 1993a). The capital cost for an enclosure for a (i.e. one) washer, with the required additional supports, was estimated to be $230,000.

The required ductwork system would consist of ductwork and elbows, a fan, knock-out drum(s), flame arrestors(s), rupture discs, supports and insulation. The following table shows the design specifications used to estimate ductwork capital costs.

DUCTWORK GENERAL DESIGN SPECIFICATIONS		
Item	**Specifications (Imperial)**	**Specifications (metric)**
minimum duct diameter	8 inches	20 centimetres
target pressure drop	20 to 40 inches of water	50 to 100 cm of water
maximum duct velocity	3,000 feet per minute	15 metres per second
duct length	1,000 feet	305 metres
elbows	2 per 100 feet	2 per 30 metres
fans per duct	1	1
flame arrestors per duct	1	1
rupture discs	1 per 100 feet	1 per 30 metres
thickness of steel	16 gauge	-

Adapted from U.S. EPA 1993a.

The U.S. EPA (1993a) calculated capital costs using stainless steel for ducts and elbows. Annualized costs for the ductwork system include utility and maintenance costs as well as annualized capital costs. The electrical requirement for the fan was calculated from the vent gas flow rate, the estimated pressure drop through the system and an electricity cost of $0.04 U.S./kW-h. Maintenance costs were assumed to consist of 0.5 hours of labour per eight hour shift. Maintenance material costs were assumed to be equal to the maintenance labour.

Low-volume gases such as concentrated non-condensible gases can also be burned in the recovery boiler. This is proven technology that has been practiced for 20 to 30 years. There is a high degree of reliability, with little down-time. There are no legal or licensing considerations. The practice is compatible with other control systems that address TRS emissions.

The total installed capital cost for collecting low-volume non-condensible gases from the digester system and evaporators, and ducting them to the lime kiln, plus the power boiler or recovery boiler (back-up) for incineration would typically be around $2,000,000 (CO #9). Engineering and installation would take about 12 months, but mill production would not be affected as the tie-ins could be made during regular mill shut downs. The equipment comes in a full range of sizes. The expected service life of the equipment is about 20 years.

High-volume/low-concentration gases can be burned in the recovery boiler or power boiler. The gases can be added to the suction end of the combustion air forced draft fan, or ducted directly to one or more special air ports. This is proven technology that has been practiced for about 10 years. There is a high degree of reliability, with little down-time. There are no legal or licensing considerations. It is compatible with other control systems that address TRS emissions.

The total installed capital cost for collecting low-volume non-condensible gases from the brownstock washers and various tank vents, and for ducting the gases to the recovery boiler or power boiler would typically be around $2,000,000 to $4,000,000 (CO #2, Blackwell 1994). U.S. EPA (1993a) reports capital costs ranging from $170,000 to $410,000 to collect emissions from the brownstock foam tank and weak black liquor tank and incinerate in an existing combustion device (CO #1). A system for collecting chip bin gases from a continuous digester, cooling it to remove most of the water vapour and ducting it to the recovery boiler and power boiler would have a capital cost of about $2,000,000 (CO #10, Blackwell 1994), typically. In all cases, engineering and installation would take about 12 months, but mill production would not be affected as the tie-ins could be made during regular mill shut downs. The equipment comes in a full range of sizes and has an expected service life of about 20 years.

Collected low volume non-condensible gases could also be vented to a tall stack such as the recovery boiler or power boiler stack. This option would require ducting and fans similar to the combustion option but without the tie-in to the combustion device. The approximate capital cost for this option is $1,000,000 (Blackwell 1994). Please note that this option will not reduce the mass loading of TRS to the environment.

3.5.8 Thermal Incinerator

While all pulping vent streams would normally be controlled by an existing combustion device, a back-up incinerator may be used to handle these streams when the other existing combustion sources are down. A thermal incinerator consists of a combustion chamber, instrumentation, a blower, a collection fan, ductwork and a stack.

Some mills install a dedicated incinerator to burn low-volume/high-concentration non-condensible gases, stripper vent gas and high-volume/low-concentration gases. Such a measure is not considered to be particularly attractive as the typical installed capital cost for the incinerator and an SO_2 scrubber is around $5,000,000 (Blackwell 1994) (CO #3). This might be done if the mill does not have a wood-waste-fired power boiler. An incinerator system usually includes an absorber to remove sulphur dioxide from the flue-gas, using caustic. The bleed stream from the absorber can be added to the mill liquor cycle as sodium and sulphur make-up, but may not be required in some cases. If the additional sodium make-up cannot be accommodated in the liquor cycle, the capital cost of the scrubber caustic could be in the range of $500,000 to $1,000,000 per year. There is also an operating cost for supplemental fossil fuel.

Dedicated incinerators and sulphur dioxide absorbers are proven technology. They have been used in a few kraft mills for the last few years. There is a high degree of reliability, with little down-time. There are no legal or licensing considerations. Design and installation takes about 12 months, but there is no impact on mill production as tie-ins can be made during scheduled mill shut downs. The incinerator system should last about 20 years, but may have to be rebricked every few years. Incinerators and absorbers come in a full range of sizes. The TRS is incinerated and VOCs are burned as well. A dedicated incinerator is compatible with other pollution control systems that address TRS emissions. It is technically feasible for any Ontario kraft mill, but the capital cost is excessive. Therefore it is considered to be a last resort for controlling TRS emissions.

Flares, as used at refineries to incinerate vent gases, have not been used much at kraft mills for non-condensible gases. As was discussed in Section 3.2.13.2, the TRS destruction efficiency is limited to 50% to 75% (Blackwell 1994). Nonetheless, a flare could be used as a back-up incineration point.

U.S. EPA 1979 provides estimated capital costs for piping batch digesters to the lime kiln with refurbished blow heat recovery and separate incineration. Assumptions are as follows:

1) multiple-effect evaporators combined with digester vents;
2) utility requirements for electricity and fuel were developed from data by an engineering construction company; and
3) fuel consumption assumed for destruction of non-condensible TRS emissions are based on use of a separate incinerator as a stand-by control device for 33 days or 10% of the time. This represents an assumed duration of down-time for the lime kiln for maintenance when the kiln becomes unavailable as a control device for incinerating TRS emissions.

3.5.9 Steam Strippers

Steam strippers are used to remove TRS and volatile components from process foul condensates. The steam stripper may be integrated into the evaporator set or may be a stand-alone system. For facilities planning to upgrade the evaporator system, it may be more cost effective to incorporate the steam stripper into that system. Otherwise, a stand-alone system may be required. The factors that affect the costs for steam stripping include the steam usage, tower height and diameter and the type of stripper (tray or packed bed). The column diameter is a function of the foul condensate feed rate and must be large enough to prevent flooding and to provide a low pressure drop. An integrated system uses steam from the evaporator set and thus uses less fresh steam than a stand-alone system.

Since the emissions from the steam stripper would be ducted to an existing combustion device, some heat value would be obtained from burning this fuel source. Due to the high moisture content of this overhead stream, some of this heat would be consumed in heating the moisture. The overhead from the stripper is normally enhanced with the use of reflux in the stripper resulting in a fuel-rich vent gas. There are extra costs for the reflux tank and its associated condenser.

Capital items for a steam stripper consist of a feed tank, head preheater, the steam stripper column (complete with platforms and ladders), the condensers, the reflux tank, the flame arrestor, the pumps and the ejector. All of the equipment would be constructed from stainless steel. The

total capital cost for a steam stripper system was calculated by U.S. EPA (1993a) to be 2.2 times the purchased equipment costs. The purchased equipment costs included the cost for the equipment components, the auxiliary piping, the instrumentation, the sales tax and the freight.

Direct annual costs for a steam stripper include utilities, labour and maintenance activities. The costs presented here (Table 3.11) assume that there is existing steam capacity and cooling water. To estimate electricity costs for the pumps and other electrical components, the (U.S.EPA 1993a) assumed a head of 37 metres of water, a pump efficiency of 64% and electrical costs of $0.04 U.S./kW-h.

The strippers are reliable, with little unscheduled down-time. It takes about 1½ years to design and install a foul condensate stripping system, but there is no impact on mill operations as the tie-ins can be made during scheduled mill shut downs. The expected physical life is 20 to 30 years. The size of a stripper can be made to suit the requirements of any mill. To improve the TRS removal efficiency, more steam has to be used; this increases the diameter of the stripper and increases the size of the overhead condensers. There are no legal or licensing considerations. Foul condensate stripping is compatible with other pollution control systems that address TRS emissions.

Foul condensate stripping is feasible for all of Ontario's kraft mills. The total installed capital cost of a steam stripping and incineration system at a 700 ADt/d mill is typically about $5,000,000 (CO #5). This cost is based on incinerating stripper vent gas in an existing lime kiln or recovery boiler. The stripper vent gases can be routed to an existing combustion device for a capital cost of approximately $400,000 (CO #15, Blackwell 1994). Installation of a dedicated incinerator adds another $5,000,000 to the capital cost; usually this is not necessary.

Depending upon how the overhead condensers are integrated with other mill heat systems, there may or may not be an operating cost for the stripper steam. The operating cost could be as high as $1,000,000 per year.

3.5.10 Summary Costs

For this assessment, the capital costs presented in Table 3.10 were converted to 1994 Canadian dollars using the cost index from Chemical Engineering magazine (see bottom of Table 3.12) and

a $Can/$U.S. of 1.4018 (Bank of Canada for 1994). The revised capital costs for each control option are presented in Table 3.12.

The main reference documents for these costs U.S. EPA (1979) and U.S. EPA (1993a) present costs for three different size mills: 500, 1,000 and 1,500 TPD (of dry pulp). All are presented here.

Each of the capital costs were annualized according to the U.S. EPA OAQPS methodology for costing as described in "*Handbook: Control Technologies for Hazardous Air Pollutants*", U.S. EPA 1991. Each calculation is shown in detail in Appendix C.

The following assumptions are used:

- Installation Cost = 0.5 × Purchased Equipment Cost (PEC)[3] (Blackwell 1994)
- Engineering = 0.1 × PEC (OAQPS)
- Construction Overhead = 0.05 × PEC (OAQPS)[4]
- Contractor Fees = 0.1 × PEC (OAQPS)
- Start-up = 0.02 × PEC (OAQPS)
- Contingencies = 0.3 × PEC (Blackwell 1994)

→ Total Capital Cost (TCC) = sum of the above costs

- Operating Labour = ½ hour/8-hour shift (OAQPS) at $40/hour (Blackwell 1994)
- Supervisor Labour = 15% of operating labour
- Maintenance Cost = 5% of TCC - standard engineering costing practice (Blackwell 1994)
- Overhead = 60% of Labour and Maintenance Costs
- Utilities (Fuel) = $3.3/ft.^{3} of natural gas (OAQPS)
- Utilities (Electricity) = $0.059/kwh (OAQPS)
- Utilities (Steam) = $4.02/Mg (U.S. EPA 1993a)
- Administrative = 2% of TCC
- Property Taxes = 1% of TCC
- Insurance = 1% of TCC

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[3] Assumes purchased equipment cost includes process equipment, tanks, pumps, fans, instrumentation control valves, piping, manual valves, ducting, electrical and building.

[4] This allowance for overhead may be included in operating labour and maintenance cost; however, this extra cost will allow for additional contingencies.

Table 3.12

Estimated Capital Costs for Pulp Mill Control Equipment ($CAN 1994)

Control Option	Estimated Control Efficiency	Estimated Capital Cost ($) Mill Size (ADT/d) 500	1000	1500	Capital Cost Adapted From	Notes
1. Combustion of emissions from brown stock foam tank, weak black liquor tank	94%	$258,000	$424,000	$621,000	U.S.EPA 1993a	
2. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in recovery boiler	94%	$1,515,000	$2,424,000	$3,182,000	U.S.EPA 1993a	
	94%		$3,000,000		Blackwell 1994	
	94%	$2,269,000	$3,782,000	$4,791,000	U.S.EPA 1979	
	94%		$4,141,000		Rainy River 1994	6
3. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in a separate incinerator	94%	$4,035,000	$6,304,000	$8,069,000	U.S.EPA 1979	
	94%		$6,000,000		Blackwell 1994	
4. Collection of emissions from brown stock washers and vent from boiler stack	0%		$1,000,000		Blackwell 1994	
5. Steam stripping of pulping wastewater followed by incineration in existing device	88%	$1,753,000	$3,788,000	$4,979,000	U.S.EPA 1993a (int)	7
	88%	$3,997,000	$8,636,000	$11,350,000	U.S.EPA 1993a(non-int)	8
	88%		$5,000,000		Blackwell 1994	
	88%		$5,383,000		Rainy River 1994	
6. Coversion to low odour recovery boiler	75%	$33,790,000	$58,753,000	$81,196,000	U.S.EPA 1979	
	75%		$35,000,000		Blackwell 1994	
	75%		$35,000,000		H.A.Simons 1994	
7. Black liquor oxidation system	99%	$1,513,000	$2,522,000	$3,782,000	U.S.EPA 1979	
	99%		$2,000,000		Blackwell 1994	
8. Control of emissions from black liquor oxidation vents	94%	$555,000	$832,000	$1,089,000	U.S.EPA 1979	1
	94%	$1,009,000	$1,412,000	$1,765,000	U.S.EPA 1979	2
	100%	$2,723,000	$4,135,000	$5,295,000	U.S.EPA 1979	3
	94%		$1,000,000		Blackwell 1994	3,9
9. Collection of batch digester/evaporator vent gases and incineration in lime kiln	94%	$1,009,000	$2,269,000	$4,035,000	U.S.EPA 1979	4
	94%	$2,269,000	$5,043,000	$8,826,000	U.S.EPA 1979	5
	94%		$2,000,000		Blackwell 1994	
	94%		$4,659,000		Rainy River 1994	
10. Collection of continuous digester vent gases and incineration	94%	$756,000	$1,009,000	$1,261,000	U.S.EPA 1979	
	94%		$2,000,000		Blackwell 1994	
11. Lime kiln process control package	80%	$189,000	$252,000	$504,000	U.S.EPA 1979	
			$500,000		Blackwell 1994	
12. Lime mud washing capacity [a]		$1,210,000	$1,841,000	$2,396,000	U.S.EPA 1979	4
		$2,421,000	$3,682,000	$4,791,000	U.S.EPA 1979	5
13. Lime mud recycle			$50,000		Blackwell 1994	
14. Large lime mud precoat filter [a]			$3,000,000		Blackwell 1994	
15. Incineration of condensate stripper emissions in existing combustion device	94%	$41,000	$57,000	$71,000	U.S.EPA 1979	
			$400,000		Blackwell 1994	
16. Switch from weak wash to caustic on the smelt dissolving tank scrubber	75%		$200,000		Blackwell 1994	

Table 3.12

Estimated Capital Costs for Pulp Mill Control Equipment ($CAN 1994)

Control Option	Estimated Control Efficiency	Estimated Capital Cost ($) Mill Size (ADT/d) 500	1000	1500	Capital Cost Adapted From	Notes
17. Small scrubber (sewer vent gas)	50-90%		$300,000		Blackwell 1994	
Small scrubber (clarifier vents, turpentine decanter vent	75%		$500,000		Blackwell 1994	
18. Large scrubber (BSW hood vents etc)	50%		$3,000,000		Blackwell 1994	
Large scrubber (black liquor tanks)	75%		$1,000,000		Blackwell 1994	
19. Recovery boiler scrubber	90%		$10,000,000		Blackwell 1994	
	90%		$7,800,000		H.A.Simons 1994	
20. New dissolving tank vent scrubber	75%		$1,656,000		Rainy River 1994	
21. Lime kiln stack venturi scrubber	80%		$4,141,000		Rainy River 1994	
22. Bleach plant stack scrubber	50%-90%		$2,588,000		Rainy River 1994	
23. Tall oil plant vent scrubber	90%		$414,000		Rainy River 1994	
24. Effluent building vent scrubber	50%-90%		$414,000		Rainy River 1994	
25. New Lime Kiln	80%		$7,565,000		U.S.EPA 1979	
			$30,000,000		Blackwell 1994	
26. New Diffusion Brown Stock Washers	99%		$20,000,000		Blackwell 1994	

ADT/d - air dried tons/day

Notes:

1 Black liquor vent gases incinerated in recovery boiler
2 Black liquor vent gases incinerated in separate incinerator
3 Black liquor oxidation with molecular oxygen
4 Low retrofit penalty
5 High retrofit penalty
6 The combustion source is not clear - this may be a separate incinerator
7 Integrated with evaporator set
8 Not integrated with evaporator set
9 Switching to oxygen instead of air

[a] same technology
Incineration 94% reduction of TRS (U.S.EPA 1993a)
Black liquor oxidation can offer 99% (Springer 1986)
U.S.EPA 1979 reports incineration of emissions from black liquor oxidations systems 80% efficient
Scrubber efficiency 80% with weak wash; using a packed bed section up to 95% (H.A.Simons 1994)
Improving lime mud washing and introducing process control have reported emission reductions of more than 80%
U.S.EPA 1979 reports 75% reduction for process controls; 94% for process controls and high efficiency mud washing
Caustic scrubbing can have removal efficiencies of 50-90% - see page 3-14 text (Blackwell 1994)
Condensate stripping - removal efficiencies of up to 94% reported (U.S.EPA 1993a) and subsequent incineration (94%) overall reduction 94.4%
Conversion to low odour boiler from black liquor oxidation (20 ppm - 5 ppm) (75%) (Blackwell 1994)
Switch from weak wash to caustic (20 ppm to 5 ppm) 75% (Blackwell 1994)
Molecular oxidation of black liquor has no vent points - closed system - 100% (U.S.EPA 1979)

Chemical Engineering Cost Index

1976	$205.80
1988	$342.50
1990	$357.60
1994	$370.20

Canadian/US conversion factor ($Can/$US)

1.4018

Capital Cost estimate from Rainy River was assumed to be in 1990 $Can.

→ Operating and Maintenance Costs (O&M) = sum of the above costs

- Capital Recovery - 10 years at 10% (Capital Recovery Factor = 0.16275) (Riggs et al. 1986)

→ Total Annualized Cost = O&M + 0.16275 × TCC

Hence, the annualized cost includes the operating and maintenance costs and the capital cost distributed over a 10-year period.

The accuracy of this method for calculating annualized costs is estimated to be ± 30% (OAQPS). Blackwell (1994) estimates the accuracy of the costing methodology to be approximately -25% to +75% tied mainly to the expected accuracy of the generalized capital costs in a specific situation.

Table 3.13 presents the operating and maintenance costs for each control option. The costs range from $17,000/year for control of condensate stripping emissions to $3,300,000/year for conversion of a low odour recovery boiler.

The annualized costs for each control option in 1994 Canadian dollars are presented in Table 3.14. The costs range from approximately $41,000/year to incinerate emissions from a condensate stripper in an existing combustion device to $17,681,000/year for conversion to a low odour recovery boiler.

The cost effectiveness of the different control options are shown in Table 3.15. Based on the estimated control efficiency for each control option and the uncontrolled emission rates (no emission control applied) for a 1,000 ADT/d pulp mill (uncontrolled emission factors as reported in Table 3.1), controlled emission rates were estimated, and the amount of TRS reduction was calculated. The cost effectiveness was determined from the annualized cost divided by the total TRS reduction (assuming 328.5 operating days/year).

The cost effectiveness is highly variable ranging from $200/t TRS for incineration of condensate stripper emissions to $74,000 to $107,000/t TRS for control of emissions from black liquor oxidation vents.

For existing facilities, the cost effectiveness could be quite different depending upon the effectiveness of the existing controls, and the site specific capital costs.

The following sections discuss specific controls and their costs for the three mills examined in this study. The control options and associated costs discussed in the following section are extracted from Tables 3.12, 3.13 and 3.14. The control options are considered to be possible based on the discussion in Section 3.2. Not all of these options are necessarily viable at each facility. Each facility should be assessed in much greater detail to determine the best control options for each process.

Most of the generalized capital costs discussed in Section 3.5 are considered to be accurate within the limits of -25% to +75%. In a specific situation, the capital cost might be as much as 75% greater than the generalized cost given here. The following section applies these estimates to the three mills examined in this study (Table 3.16, 3.17, 3.18). This should be kept in mind when reviewing the costs for each facility. These costs are intended to be only a broad estimate. The actual cost at any facility could vary significantly from what is presented here, depending on the mill configuration and the age and capacity of the process equipment.

Emissions from tall sources are usually unaffected by the influences of surrounding buildings and terrain changes that may effect dispersion (e.g. building wake), and consequently travel some distance downwind (several hundred meters) before reaching a maximum near the ground. The recovery boiler and lime kiln generally emit pollutants through tall sources. Emissions from all other sources may be trapped within the building wake. The concentrations from these types of sources are a maximum close to the building and thus contribute significantly to the GLC at the property line. For this reason both the property line and the GLCs several hundred meters away are presented for Rainy River and Domtar. Malette has a large property, so that the maximum GLC (contribution from all sources) coincides with the property line.

The discussions for Rainy River and Domtar present different control options for the sources which contribute the most to the GLC (both at the property line and further downwind). The control options considered are referred to by a CO# (control option) throughout the discussion. Tables 3.19 and 3.20 show the reduction in the GLCs and associated costs that the control options (CO#) would provide. The control equipment assumed for the present control options are also indicated on Tables 3.19 and 3.20.

Table 3.13

Estimated Operating and Maintenance Costs for Pulp Mill Control Equipment ($CAN 1994)

Control Option	Estimated Control Efficiency	Estimated Operating & Maintenance Cost ($/year) Mill Size (ADT/d) 500	1000	1500	Capital Cost Adapted From	Notes	Appendix C Table* (Cost Details)
1. Combustion of emissions from brown stock foam tank, weak black liquor tank	94%	$38,000	$58,000	$81,000	U.S.EPA 1993a		1-3
2. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in recovery boiler	94%	$243,000	$352,000	$443,000	U.S.EPA 1993a		4-6
	94%		$457,000		Blackwell 1994		7
	94%	$353,000	$534,000	$656,000	U.S.EPA 1979		8-10
	94%		$638,000		Rainy River 1994	6	11
3. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in a separate incinerator	94%	$2,550,000	$2,822,000	$3,034,000	U.S.EPA 1979		12-14
	94%		$1,442,000		Blackwell 1994		15
4. Collection of emissions from brown stock washers and vent from boiler stack	0%		$217,000		Blackwell 1994		80
5. Steam stripping of pulping wastewater followed by incineration in existing device	88%	$437,000	$757,000	$953,000	U.S.EPA 1993a (int)	7	16-18
	88%	$2,553,000	$3,988,000	$4,929,000	U.S.EPA 1993a(non-int)	8	19-21
	88%		$3,588,000		Blackwell 1994		22
	88%		$3,634,000		Rainy River 1994		23
6. Coversion to low odour recovery boiler	75%	$2,570,000	$3,568,000	$4,466,000	U.S.EPA 1979		24-26
	75%		$5,419,000		Blackwell 1994		27
	75%		$5,418,000		H.A.Simons 1994		28
7. Black liquor oxidation system	99%	$399,000	$469,000	$557,000	U.S.EPA 1979		29-31
	99%		$555,000		Blackwell 1994		32
8. Control of emissions from black liquor oxidation vents	94%	$207,000	$240,000	$271,000	U.S.EPA 1979	1	33-35
	94%	$760,000	$809,000	$851,000	U.S.EPA 1979	2	36-38
	100%	$751,000	$920,000	$1,059,000	U.S.EPA 1979	3	39-41
	94%		$544,000		Blackwell 1994	3,9	42
9. Collection of batch digester/evaporator vent gases and incineration in lime kiln	94%	$213,000	$214,000	$285,000	U.S.EPA 1979	4	43-45
	94%	$365,000	$325,000	$477,000	U.S.EPA 1979	5	46-48
	94%		$332,000		Blackwell 1994		49
	94%		$651,000		Rainy River 1994		50
10. Collection of continuous digester vent gases and incineration	94%	$183,000	$164,000	$174,000	U.S.EPA 1979		51-53
	94%		$332,000		Blackwell 1994		54
11. Lime kiln process control package	80%	$218,000	$220,000	$230,000	U.S.EPA 1979		55-57
			$96,000		Blackwell 1994		58
12. Lime mud washing capacity [a]		$105,000	$130,000	$152,000	U.S.EPA 1979	4	59-61
		$153,000	$204,000	$248,000	U.S.EPA 1979	5	62-64
13. Lime mud recycle			$42,000		Blackwell 1994		65
14. Large lime mud precoat filter [a]			$396,000		Blackwell 1994		66
15. Incineration of condensate stripper emissions in existing combustion device	94%	$17,000	$18,000	$19,000	U.S.EPA 1979		67-69
			$32,000		Blackwell 1994		84

Table 3.13

Estimated Operating and Maintenance Costs for Pulp Mill Control Equipment ($CAN 1994)

Control Option	Estimated Control Efficiency	Estimated Operating & Maintenance Cost ($/year) Mill Size (ADT/d) 500	1000	1500	Capital Cost Adapted From	Notes	Appendix C Table* (Cost Details)
16. Switch from weak wash to caustic on the smelt dissolving tank scrubber	75%		$260,000		Blackwell 1994		70
17. Small scrubber (sewer vent gas)	50-90%		$72,000		Blackwell 1994		71
Small scrubber (clarifier vents, turpentine decanter	75%		$96,000		Blackwell 1994		85
18. Large scrubber (BSW hood vents etc)	50%		$420,000		Blackwell 1994		72
Large scrubber (black liquor tanks)	75%		$180,000		Blackwell 1994		86
19. Recovery boiler scrubber	90%		$1,337,000		Blackwell 1994		73
	90%		$1,073,000		H.A.Simons 1994		74
20. New smelt dissolving tank vent scrubber	75%		$245,000		Rainy River 1994		75
21. Lime kiln stack venturi scrubber	80%		$548,000		Rainy River 1994		76
22. Bleach plant stack scrubber	50%-90%		$358,000		Rainy River 1994		77
23. Tall oil plant vent scrubber	90%		$87,000		Rainy River 1994		78
24. Effluent building vent scrubber	50%-90%		$86,000		Rainy River 1994		79
25. New Lime Kiln	80%		$944,000		U.S.EPA 1979		81
			$3,636,000		Blackwell 1994		82
26. New Diffusion Brown Stock Washers	99%		$2,497,000		Blackwell 1994		83

ADT/d - air dried tons/day

Notes:

1 Black liquor vent gases incinerated in recovery boiler
2 Black liquor vent gases incinerated in separate incinerator
3 Black liquor oxidation with molecular oxygen
4 Low retrofit penalty
5 High retrofit penalty
6 The combustion source is not clear - this may be a separate incinerator
7 Integrated with evaporator set
8 Not integrated with evaporator set
9 switching to oxygen instead of air

[a] same technology

Incineration 94% reduction of TRS (U.S.EPA 1993a);>98% (Blackwell 1994)
Black liquor oxidation can offer 99% (Springer 1986)
U.S.EPA 1979 reports incineration of emissions from black liquor oxidations systems 80% efficient
Scrubber efficiency 80% with weak wash; using a packed bed section up to 95% (H.A.Simons 1994)
Improving lime mud washing and introducing process control have reported emission reductions of more than 80%
U.S.EPA 1979 reports 75% reduction for lime kiln process controls; 94% for process controls and high efficiency mud washing
Caustic scrubbing can have removal efficiencies of 50-90% - see page 3-14 text (Blackwell 1994)
Condensate stripping - removal efficiencies of up to 94% reported (U.S.EPA 1993a) and subsequent incineration (94%) overall reduction 94.4%
Conversion to low odour boiler from black liquor oxidation (20 ppm - 5 ppm) (75%) (Blackwell 1994)
Switch from weak wash to caustic (20 ppm to 5 ppm) 75% (Blackwell 1994)
Molecular oxidation of black liquor has no vent points - closed system - 100% (U.S.EPA 1979)

Table 3.14

Estimated Annualized Costs for Pulp Mill Control Equipment ($CAN 1994)
(Annualized cost includes operating and maintenance costs and capital costs distributed over a 10 year period)

Control Option	Estimated Control Efficiency	Estimated Annualized Cost ($/year) Mill Size (ADT/d) 500	1000	1500	Capital Cost Adapted From	Notes	Appendix C Table* (Cost Details)
1. Combustion of emissions from brown stock foam tank, weak black liquor tank	94%	$80,000	$127,000	$182,000	U.S.EPA 1993a		1-3
2. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in recovery boiler	94%	$490,000	$747,000	$961,000	U.S.EPA 1993a		4-6
	94%		$945,000		Blackwell 1994		7
	94%	$722,000	$1,150,000	$1,436,000	U.S.EPA 1979		8-10
	94%		$1,312,000		Rainy River 1994	6	11
3. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in a separate incinerator	94%	$3,206,000	$3,847,000	$4,346,000	U.S.EPA 1979		12-14
	94%		$3,698,000		Blackwell 1994		15
4. Collection of emissions from brown stock washers and vent from boiler stack	0%		$380,000		Blackwell 1994		80
5. Steam stripping of pulping wastewater followed by incineration in existing device	88%	$611,000	$1,262,000	$1,652,000	U.S.EPA 1993a (int)	7	16-18
	88%	$3,092,000	$5,282,000	$6,665,000	U.S.EPA 1993a(non-int)	8	19-21
	88%		$4,291,000		Blackwell 1994		22
	88%		$4,399,000		Rainy River 1994		23
6. Coversion to low odour recovery boiler	75%	$8,069,000	$13,130,000	$17,681,000	U.S.EPA 1979		24-26
	75%		$11,115,000		Blackwell 1994		27
	75%		$11,114,000		H.A.Simons 1994		28
7. Black liquor oxidation system	99%	$645,000	$879,000	$1,173,000	U.S.EPA 1979		29-31
	99%		$881,000		Blackwell 1994		32
8. Control of emissions from black liquor oxidation vents	94%	$297,000	$375,000	$448,000	U.S.EPA 1979	1	33-35
	94%	$924,000	$1,039,000	$1,138,000	U.S.EPA 1979	2	36-38
	100%	$1,194,000	$1,593,000	$1,921,000	U.S.EPA 1979	3	39-41
	94%		$907,000		Blackwell 1994	3,9	42
9. Collection of batch digester/evaporator vent gases and incineration in lime kiln	94%	$377,000	$583,000	$942,000	U.S.EPA 1979	4	43-45
	94%	$734,000	$1,146,000	$1,913,000	U.S.EPA 1979	5	46-48
	94%		$658,000		Blackwell 1994		49
	94%		$1,409,000		Rainy River 1994		50
10. Collection of continuous digester vent gases and incineration	94%	$306,000	$328,000	$379,000	U.S.EPA 1979		51-53
	94%		$658,000		Blackwell 1994		54
11. Lime kiln process control package	80%	$249,000	$261,000	$312,000	U.S.EPA 1979		55-57
			$177,000		Blackwell 1994		58
12. Lime mud washing capacity [a]		$105,000	$130,000	$152,000	U.S.EPA 1979	4	59-61
		$547,000	$803,000	$1,027,000	U.S.EPA 1979	5	62-64
13. Lime mud recycle			$50,000		Blackwell 1994		65
14 Large lime mud precoat filter [a]			$884,000		Blackwell 1994		66
15. Incineration of condensate stripper emissions in existing combustion device	94%	$41,000	$45,000	$50,000	U.S.EPA 1979		67-69
			$129,000		Blackwell 1994		84
16. Switch from weak wash to caustic on the smelt dissolving tank scrubber	75%		$293,000		Blackwell 1994		70

Table 3.14

Estimated Annualized Costs for Pulp Mill Control Equipment ($CAN 1994)

(Annualized cost includes operating and maintenance costs and capital costs distributed over a 10 year period)

Control Option	Estimated Control Efficiency	Estimated Annualized Cost ($/year) Mill Size (ADT/d) 500	1000	1500	Capital Cost Adapted From	Notes	Appendix C Table* (Cost Details)
17. Small scrubber (sewer vent gas)	50-90%		$121,000		Blackwell 1994		71
Small scrubber (clarifier vents, turpentine decanter vent	75%		$177,000		Blackwell 1994		85
18. Large scrubber (BSW hood vents etc)	65%		$908,000		Blackwell 1994		72
Large scrubber (black liquor tanks)	75%		$343,000		Blackwell 1994		86
19. Recovery boiler scrubber	90%		$2,965,000		Blackwell 1994		73
	90%		$2,342,000		H.A.Simons 1994		74
20. New smelt dissolving tank vent scrubber	75%		$515,000		Rainy River 1994		75
21. Lime kiln stack venturi scrubber	80%		$1,222,000		Rainy River 1994		76
22. Bleach plant stack scrubber	50%-90%		$779,000		Rainy River 1994		77
23. Tall oil plant vent scrubber	90%		$154,000		Rainy River 1994		78
24. Effluent building vent scrubber	50%-90%		$153,000		Rainy River 1994		79
25. New Lime Kiln	80%		$2,175,000		U.S.EPA 1979		81
			$8,519,000		Blackwell 1994		82
26. New Diffusion Brown Stock Washers	99%		$5,752,000		Blackwell 1994		83

ADT/d - air dried tons/day

Notes:

1 Black liquor vent gases incinerated in recovery boiler
2 Black liquor vent gases incinerated in separate incinerator
3 Black liquor oxidation with molecular oxygen
4 Low retrofit penalty
5 High retrofit penalty
6 The combustion source is not clear - this may be a separate incinerator
7 Integrated with evaporator set
8 Not integrated with evaporator set
9 switching to oxygen instead of air

* same technology

Incineration 94% reduction of TRS (U.S.EPA 1993a)

Black liquor oxidation can offer 99% (Springer 1986)

U.S.EPA 1979 reports incineration of emissions from black liquor oxidations systems 80% efficient

Scrubber efficiency 80% with weak wash; using a packed bed section up to 95% (H.A.Simons 1994)

Improving lime mud washing and introducing process control have reported emission reductions of more than 80%

U.S.EPA 1979 reports 75% reduction for process controls; 94% for process controls and high efficiency mud washing

Caustic scrubbing can have removal efficiencies of 50-90% - see page 3-14 text (Blackwell 1994)

Condensate stripping - removal efficiencies of up to 94% reported (U.S.EPA 1993a) and subsequent incineration (94%) overall reduction 94.4%

Conversion to low odour boiler from black liquor oxidation (20 ppm - 5 ppm) (75%) (Blackwell 1994)

Switch from weak wash to caustic (20 ppm to 5 ppm) 75% (Blackwell 1994)

Molecular oxidation of black liquor has no vent points - closed system - 100% (U.S.EPA 1979)

Table 3.15

Estimated Cost Effectiveness for Pulp Mill Control Equipment ($CAN 1994) (1000 ADT/d Pulp Mill)
(Annualized cost includes operating and maintenance costs and capital costs distributed over a 10 year period)

Control Option	Estimated Control Efficiency	Uncontrolled Emission Rate (kg TRS/t pulp)	Uncontrolled Emission Rate (kg TRS/d)	Controlled Emission Rate (kg TRS/d)	Total Emissions Reduction (t TRS/y)	Annualized Cost ($/year)*	Estimated Cost For Emission Control ($/t TRS)*	Capital Cost Adapted From	Notes
1. Combustion of emissions from brown stock foam tank, weak black liquor tank	94%	0.22	200	12	62	$127,000	$2,000	U.S.EPA 1993a	
2. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in recovery boiler	94%	1.75	1591	95	491	$747,000	$2,000	U.S.EPA 1993a	
	94%	1.75	1591	95	491	$945,000	$2,000	Blackwell 1994	
	94%	1.75	1591	95	491	$1,150,000	$2,000	U.S.EPA 1979	
	94%	1.75	1591	95	491	$1,312,000	$3,000	Rainy River 1994	6
3. Combustion of emissions from brown stock washers, knotter, deckers/screens destruction in a separate incinerator	94%	1.75	1591	95	491	$3,847,000	$8,000	U.S.EPA 1979	
	94%	1.75	1591	95	491	$3,698,000	$8,000	Blackwell 1994	
4. Collection of emissions from brown stock washers and vent from boiler stack	0%	1.75	1591	1591	0		N/A	Blackwell 1994	
5. Steam stripping of pulping wastewater followed by incineration in existing device	88%	1.18	1073	129	310	$1,262,000	$4,000	U.S.EPA 1993a (int)	7
	88%	1.18	1073	129	310	$5,282,000	$17,000	U.S.EPA 1993a(non-int)	8
	88%	1.18	1073	129	310	$4,291,000	$14,000	Blackwell 1994	
	88%	1.18	1073	129	310	$4,399,000	$14,000	Rainy River 1994	
6. Coversion to low odour recovery boiler	75%	7.50	6818	1705	1680	$13,130,000	$8,000	U.S.EPA 1979	
	75%	7.50	6818	1705	1680	$11,115,000	$7,000	Blackwell 1994	
	75%	7.50	6818	1705	1680	$11,114,000	$7,000	H.A.Simons 1994	
7. Black liquor oxidation system	99%	7.50	6818	68	2217	$879,000	$400	U.S.EPA 1979	
	99%	7.50	6818	68	2217	$881,000	$400	Blackwell 1994	
8. Control of emissions from black liquor oxidation vents	94%	0.05	45	3	14	$375,000	$27,000	U.S.EPA 1979	1
	94%	0.05	45	3	14	$1,039,000	$74,000	U.S.EPA 1979	2
	100%	0.05	45	0	15	$1,593,000	$107,000	U.S.EPA 1979	3
	94%	0.05	45	3	14	$907,000	$65,000	Blackwell 1994	3,9
9. Collection of batch digester/evaporator vent gases and incineration in lime kiln	94%	3.20	2905	174	897	$583,000	$1,000	U.S.EPA 1979	4
	94%	3.20	2905	174	897	$1,146,000	$1,000	U.S.EPA 1979	5
	94%	3.20	2905	174	897	$658,000	$1,000	Blackwell 1994	
	94%	3.20	2905	174	897	$1,409,000	$2,000	Rainy River 1994	
10. Collection of continuous digester vent gases and incineration	94%	3.20	2909	175	898	$328,000	$400	U.S.EPA 1979	
	94%	3.20	2909	175	898	$658,000	$1,000	Blackwell 1993	
11. Lime kiln process control package	80%	0.40	364	73	96	$130,000	$7,000	U.S.EPA 1979	
								Blackwell 1994	
12. Lime mud washing capacity [a]								U.S.EPA 1979	4
								U.S.EPA 1979	5
13. Lime mud recycle								Blackwell 1994	
14 Large lime mud precoat filter [a]								Blackwell 1994	
15. Incineration of condensate stripper emissions in existing combustion device	94%	1.00	909	55	281	$45,000	$200	U.S.EPA 1979	
	94%	1.00	909	55	281	$129,000	$500	Blackwell 1994	
16. Switch from weak wash to caustic on the smelt dissolving tank scrubber	75%	0.14	127	32	31	$293,000	$9,000	Blackwell 1994	
17. Small scrubber (sewer vent gas)	50-90%							Blackwell 1994	
Small scrubber (clarifier vents, turpentine decanter vent)	75%							Blackwell 1994	

Table 3.15

Estimated Cost Effectiveness for Pulp Mill Control Equipment ($CAN 1994) (1000 ADT/d Pulp Mill)
(Annualized cost includes operating and maintenance costs and capital costs distributed over a 10 year period)

Control Option	Estimated Control Efficiency	Uncontrolled Emission Rate (kg TRS/t pulp)	Uncontrolled Emission Rate (kg TRS/d)	Controlled Emission Rate (kg TRS/d)	Total Emissions Reduction (t TRS/y)	Annualized Cost ($/year)*	Estimated Cost For Emission Control ($/t TRS)*	Capital Cost Adapted From	Notes
18. Large scrubber (BSW hood vents etc)	65%							Blackwell 1994	
Large scrubber (black liquor tanks)	75%							Blackwell 1994	
19. Recovery boiler scrubber	90%	7.50	6818	682	2016	$2,965,000	$1,000	Blackwell 1994	
	90%	7.50	6818	682	2016	$2,342,000	$1,000	H.A.Simons 1994	
20. New smelt dissolving tank vent scrubber	75%	0.10	91	23	22	$515,000	$23,000	Rainy River 1994	
21. Lime kiln stack venturi scrubber	80%	0.40	364	73	96	$1,222,000	$13,000	Rainy River 1994	
22. Bleach plant stack scrubber	50%-90%							Rainy River 1994	
23. Tall oil plant vent scrubber	90%	0.10	91	9	27	$154,000	$6,000	Rainy River 1994	
24. Effluent building vent scrubber	50%-90%							Rainy River 1994	
25. New Lime Kiln	80%	0.40	364	73	96	$2,175,000	$23,000	U.S.EPA 1979	
	80%	0.40	364	73	96	$8,519,000	$89,000	Blackwell 1994	
26. New Diffusion Brown Stock Washers	99%	1.75	1591	16	517	$5,752,000	$11,000	Blackwell 1994	

ADT/d - ton/day; t - tonne

* rounded to the nearest $1000

Notes:

1 Black liquor vent gases incinerated in recovery boiler
2 Black liquor vent gases incinerated in separate incinerator
3 Black liquor oxidation with molecular oxygen
4 Low retrofit penalty
5 High retrofit penalty
6 The combustion source is not clear - this may be a separate incinerator
7 Integrated with evaporator set
8 Not integrated with evaporator set
9 switching to oxygen instead of air
' same technology

Uncontrolled Emission Factors from Table 3.1

Incineration 94% reduction of TRS (U.S.EPA 1993a)
Black liquor oxidation can offer 99% (Springer 1986)
U.S.EPA 1979 reports incineration of emissions from black liquor oxidations systems 80% efficient
Scrubber efficiency 80% with weak wash; using a packed bed section up to 95% (H.A.Simons 1994)
Improving lime mud washing and introducing process control have reported emission reductions of more than 80%
U.S.EPA 1979 reports 75% reduction for process controls; 94% for process controls and high efficiency mud washing
Caustic scrubbing can have removal efficiencies of 50-90% - see page 3-14 text (Blackwell 1994)
Condensate stripping - removal efficiencies of up to 94% reported (U.S.EPA 1993a) and subsequent incineration (94%) overall reduction 94.4%
Conversion to low odour boiler from black liquor oxidation (20 ppm - 5 ppm) (75%) (Blackwell 1994)
Flare efficiency 50-75% (Blackwell 1994)
Switch from weak wash to caustic (20 ppm to 5 ppm) 75% (Blackwell 1994)
Molecular oxidation of black liquor has no vent points - closed system - 100% (U.S.EPA 1979)

Table 3.16

Rainy River Forest Products Inc. Control Costs ($CAN 1994)

TRS Emission Source	TRS Emission Rate		Control Options Options	Estimated Efficiency	Controlled Emission Rate		Range of Capital Costs ($) Based on Table 3.12		Range of Operating And Maintenance Costs (± 30%) ($/year) Based on Table 3.13		Range of Annualized Costs (± 30%) ($/year) Based on Table 3.14		TRS removed	Cost Effectiveness ($/t TRS removed)	
	(g/s)	(ppm)			g/s	ppm	minimum	maximum	minimum	maximum	minimum	maximum	t/y	minimum	maximum
Brown Stock Washer Stack	0.0556	3	1. Collection and Destruction in Recovery Boiler	94%	0.003	0.2	$1,515,000	$4,141,000	$243,000	$638,000	$490,000	$1,312,000	1.5	$330,000	$884,000
			2. Collection and Destruction in Incinerator	94%	0.00	0	$4,035,000		$2,550,000		$3,206,000		1.5	$2,161,000	
			3. Collect and Vent Through boiler stack	0%	0.06	3	$1,000,000		$217,000		$380,000		0.0	none removed	
			4. New scrubber combined with bleach plant gases	75%	0.01	1	$3,000,000		$420,000		$908,000		1.2	$767,000	
			5. Replace BSW with Diffusion Washers	99%	0.001	0.03	$20,000,000		$2,497,000		$5,752,000		1.6	$3,682,000	
Weak Black Liquor Tank[3]	0.002	29	1. Collection and Destruction in Recovery Boiler	94%	0.0001	2	$258,000		$38,000		$80,000		0.05	$1,499,000	
Strong Black Liquor Tank[3]	0.0053	77	1. Collection and Destruction in Recovery Boiler	94%	0.0003	5	$258,000		$38,000		$80,000		0.14	$566,000	
			2. Collection and New Scrubber	75%	0.001	19	$1,000,000		$180,000		$343,000		0.11	$3,040,000	
Impounding Tank Vent	0.0167	31	1. Collection and Destruction in Recovery Boiler	94%	0.001	2	$258,000		$38,000		$80,000		0.45	$180,000	
			2. Steam Stripper[2]	88%	0.002	4	$5,383,000		$3,634,000		$4,399,000		0.42	$10,546,000	
			3. Collection and New Scrubber	75%	0.004	8	$300,000		$72,000		$121,000		0.36	$340,000	
Bleach Plant Scrubber	0.0386	4	1. Collection and Destruction in Recovery Boiler	94%	0.002	0.2	$258,000		$38,000		$80,000		1.0	$78,000	
Recovery Boiler Stack	0.1563	2	1. Below NSPS												
Smelt Dissolving Tank	0.1621	20	1. New Scrubber	75%	0.04	5	$1,656,000		$245,000		$515,000		3.5	$149,000	
			2. Use of caustic in scrubber	75%	0.04	5	$200,000		$260,000		$293,000		3.5	$85,000	
Lime Kiln Scrubber Stack	0.0956	8	1. At NSPS												
Tall Oil Scrubber Vent	0.0049	7	1. Collection and Destruction in Recovery Boiler	94%	0.0003	0.4	$258,000		$38,000		$80,000		0.1	$612,000	
			2. Use of caustic in scrubber	65%	0.002	2	$200,000		$260,000		$293,000		0.1	$3,241,000	
Clarifier Vents[1]	0.0184	90	1. Collection and Destruction in Recovery Boiler	94%	0.001	5	$258,000		$38,000		$80,000		0.5	$163,000	
			2. New Scrubber	75%	0.005	23	$500,000		$96,000		$177,000		0.4	$452,000	
Effluent Pumphouse Vent	0.0745	1,207	1. Steam Stripper	88%	0.009	145	$5,383,000		$3,634,000		$4,399,000		1.9	$2,364,000	
			2. Collection and Destruction in Recovery Boiler	94%	0.004	72	$258,000		$38,000		$80,000		2.0	$40,000	
			3. New Scrubber	65%	0.026	422	$414,000		$86,000		$153,000		1.4	$111,000	
			4. Steam Stripper and Scrubber	96%	0.003	48	$5,797,000		$3,720,000		$4,552,000		2.0	$2,242,000	

[1] It is not clear from the reports which clarifier vents this refers to - assumed recausticizer clarifier vent

[2] Costs will be offset by reduction in effluent pumphouse vent emissions also

[3] Vent gases could also be combined with smelt dissolving tank vent gases

Annualized cost includes operating and maintenance cost and capital cost distributed over 10 years

Table 3.17

Malette Kraft Pulp and Power Control Costs ($CAN 1994)

TRS Emission Source	TRS Emission Rate		Control Options	Estimated Efficiency	Controlled Emission Rate		Range of Capital Costs ($) Based on Table 3.12		Range of Operating And Maintenance Costs (± 30%) ($/year) Based on Table 3.13		Range of Annualized Costs (± 30%) ($/year) Based on Table 3.14		TRS removed	Cost Effectiveness ($/t TRS removed)	
	(g/s)	(ppm)			g/s	ppm	minimum	maximum	minimum	maximum	minimum	maximum	t/y	minimum	maximum
Brown Stock Units 1&2	0.062	3.55	1. Collection and Destruction in Recovery Boiler	94%	0.004	0.2	$1,515,000	$4,141,000	$243,000	$638,000	$490,000	$1,312,000	1.7	$296,000	$793,000
			2. Collection and Destruction in Incinerator	94%	0.004	0.2	$4,035,000		$2,550,000		$3,206,000		1.7	$1,938,000	
			3. Collect and Vent Through boiler stack	0%	0.06	4	$1,000,000		$217,000		$380,000		0.0	none removed	
			4. New Scrubber	65%	0.02	1.2	$3,000,000		$420,000		$908,000		1.1	$794,000	
			5. Replace BSW with Diffusion Washers	99%	0.001	0.04	$20,000,000		$2,497,000		$5,752,000		1.7	$3,302,000	
Brown Stock Unit 3	0.93	67.7	1. Collection and Destruction in Recovery Boiler	94%	0.056	4.1	$1,515,000	$4,141,000	$243,000	$638,000	$490,000	$1,312,000	25	$20,000	$53,000
			2. Collection and Destruction in Incinerator	94%	0.06	4	$4,035,000		$2,550,000		$3,206,000		25	$129,000	
			3. Collect and Vent Through boiler stack	0%	0.93	68	$1,000,000		$217,000		$380,000		0.0	none removed	
			4. New Scrubber	65%	0.33	24	$3,000,000		$420,000		$908,000		17	$53,000	
			5. Replace BSW with Diffusion Washers	99%	0.01	1	$20,000,000		$2,497,000		$5,752,000		26	$220,000	
Old Recovery Boiler With Scrubber (50% control)	1.56	23	1. Black Liquor Oxidation System (up to 90%)	0%	1.56	23	$2,000,000	$2,500,000	$469,000	$555,000	$879,000	$881,000	0	none removed	
			2. Conversion to Low Odour Recovery Boiler (>75%)	80%	0.31	5	$23,790,000	$58,753,000	$2,570,000	$5,419,000	$8,069,000	$13,130,000	35	$228,000	$371,000
New Recovery Boiler	0.0164	0.41	1. Below NSPS												
Smelt Dissolving Tank	0.21	81	1. Use of caustic in scrubber	90%	0.02	8	$200,000		$260,000		$293,000		5.4	$55,000	
Lime Kiln with ESP	0.054	10	1. Lime Kiln Controls Package (just above NSPS)												

Annualized cost includes operating and maintenance cost and capital cost distributed over 10 years

Table 3.18

Domtar Packaging Control Costs ($CAN 1994)

TRS Emission Source	TRS Emission Rate		Control Options Options	Estimated Efficiency	Controlled Emission Rate		Range of Capital Costs ($) Based on Table 3.12		Range of Operating And Maintenance Costs (± 30%) ($/year) Based on Table 3.13		Range of Annualized Costs (± 30%) ($/year) Based on Table 3.14		TRS removed	Cost Effectiveness ($/t TRS removed)	
	(g/s)	(ppm)			g/s	ppm	minimum	maximum	minimum	maximum	minimum	maximum	t/y	minimum	maximum
No. 8&9 M&D Washer Hood	0.027	4	1. Collection and Destruction in Recovery Boiler	94%	0.002	0.3	$1,515,000	$4,141,000	$243,000	$638,000	$490,000	$1,312,000	0.7	$680,000	$1,821,000
			2. Collection and Destruction in Incinerator	94%	0.00	0.3	$4,035,000		$2,550,000		$3,206,000		0.7	$4,451,000	
			3. Collect and Vent Through boiler stack	0%	0.03	4	$1,000,000		$217,000		$380,000		0.0	none removed	
			4. New Scrubber	65%	0.01	1.47	$3,000,000		$420,000		$908,000		0.5	$1,823,000	
			5. Replace BSW with Diffusion Washers	99%	0.0003	0.04	$20,000,000		$2,497,000		$5,752,000		0.8	$7,582,000	
No. 10 M&D Washer Hood	0.028	5	1. Collection and Destruction in Recovery Boiler	94%	0.002	0.3	$1,515,000	$4,141,000	$243,000	$638,000	$490,000	$1,312,000	0.7	$656,000	$1,756,000
			2. Collection and Destruction in Incinerator	94%	0.00	0.3	$4,035,000		$2,550,000		$3,206,000		0.7	$4,292,000	
			3. Collect and Vent Through boiler stack	0%	0.03	5	$1,000,000		$217,000		$380,000		0.0	none removed	
			4. New Scrubber	65%	0.01	1.68	$3,000,000		$420,000		$908,000		0.5	$1,758,000	
			5. Replace BSW with Diffusion Washers	99%	0.0003	0.04	$20,000,000		$2,497,000		$5,752,000		0.8	$7,311,000	
M&D Foam Tank Vent	0.022	114	1. Collection and Destruction in Recovery Boiler	94%	0.001	7	$258,000		$38,000		$80,000		0.6	$136,000	
			2. New Scrubber	75%	0.006	29	$300,000		$72,000		$121,000		0.5	$258,000	
No. 5&6 Hardstock Washer Hood	0.008	2	1. Collection and Destruction in Recovery Boiler	94%	0.000	0.1	$1,515,000	$4,141,000	$243,000	$638,000	$490,000	$1,312,000	0.2	$2,296,000	$6,147,000
			2. Collection and Destruction in Incinerator	94%	0.00	0.1	$4,035,000		$2,550,000		$3,206,000		0.2	$15,021,000	
			3. Collect and Vent Through boiler stack	0%	0.01	2	$1,000,000		$217,000		$380,000		0.0	none removed	
			4. New Scrubber	65%	0.00	0.60	$3,000,000		$420,000		$908,000		0.1	$6,152,000	
			5. Replace BSW with Diffusion Washers	99%	0.0001	0.04	$20,000,000		$2,497,000		$5,752,000		0.2	$25,588,000	
No. 7 Hardstock Washer Hood	0.039	4	1. Collection and Destruction in Recovery Boiler	94%	0.002	0.2	$1,515,000	$4,141,000	$243,000	$638,000	$490,000	$1,312,000	1.0	$471,000	$1,261,000
			2. Collection and Destruction in Incinerator	94%	0.00	0.2	$4,035,000		$2,550,000		$3,206,000		1.0	$3,081,000	
			3. Collect and Vent Through boiler stack	0%	0.04	4	$1,000,000		$217,000		$380,000		0.0	none removed	
			4. New Scrubber	65%	0.01	1.26	$3,000,000		$420,000		$908,000		0.7	$1,262,000	
			5. Replace BSW with Diffusion Washers	99%	0.0004	0.04	$20,000,000		$2,497,000		$5,752,000		1.1	$5,249,000	
Hardstock Foam Tank Vent	0.034	105	1. Collection and Destruction in Recovery Boiler	94%	0.002	6	$258,000		$38,000		$80,000		0.9	$88,000	
			2. New Scrubber	65%	0.012	37	$300,000		$72,000		$121,000		0.6	$193,000	
Turpentine Decanter Vent	0.12	28,700	1. Collection and Destruction in Incinerator	94%	0.007	1722.0	$4,035,000		$2,550,000		$3,206,000		3.2	$1,001,000	
			2. Gas collection and new scrubber	75%	0.030	7175	$500,000		$96,000		$177,000		2.6	$69,000	

Table 3.18

Domtar Packaging Control Costs ($CAN 1994)

TRS Emission Source	TRS Emission Rate		Control Options Options	Estimated Efficiency	Controlled Emission Rate		Range of Capital Costs ($) Based on Table 3.12		Range of Operating And Maintenance Costs (± 30%) ($/year) Based on Table 3.13		Range of Annualized Costs (± 30%) ($/year) Based on Table 3.14		TRS removed	Cost Effectiveness ($/t TRS removed)	
	(g/s)	(ppm)			g/s	ppm	minimum	maximum	minimum	maximum	minimum	maximum	t/y	minimum	maximum
Recovery Boiler Stack (above NSPS)	0.67	12	1. Improved Combustion Control[1] 2. New Scrubber	60% 75%	0.268 0.168	5 3	$7,800,000	$10,000,000	$1,073,000	$1,337,000	? $2,342,000	? $2,965,000	14.3	$164,000	$208,000
Smelt Dissolving Tank Smelt Dissolving (without concentrator)	0.56	53	1. Use of caustic in existing scrubber	90%	0.056	5	$200,000		$260,000		$293,000		14.3	$20,000	
Green Liquor Clarifier Vent[2]	0.0006	14	1. Collection and Destruction in Recovery Boiler	94%	0.00004	0.8	$258,000	$424,000	$38,000	$81,000	$127,000	$182,000	0.02	$7,934,000	$11,370,000
			2. New Scrubber	75%	0.00015	4	$300,000		$72,000		$121,000		0.01	$9,474,000	
No. 1 Causticizer Vent	0.0003	41	1. Collection and Destruction in incinerator	94%	0.00002	2.5	$4,035,000		$2,550,000		$3,206,000		0.01	$400,558,000	
			2. New Scrubber	75%	0.000075	10	$300,000		$72,000		$121,000		0.01	$18,948,000	
No. 3 Causticizer Vent	0.0015	37	1. Collection and Destruction in incinerator	94%	0.00009	2.2	$4,035,000		$2,550,000		$3,206,000		0.04	$80,112,000	
			2. New Scrubber	75%	0.000375	9	$300,000		$72,000		$121,000		0.03	$3,790,000	
Lime Mud Filter Hood Vent[3]	0.0009	0.6	1. New Scrubber	75%	0.0002	0.2	$300,000	$3,000,000	$72,000	$420,000	$121,000	$908,000	0.02	$6,316,000	$47,395,000
No. 2 Lime Kiln Stack	0.74	64	1. Lime Kiln Control Package 2. New Lime Mud Filter 3. Lime Mud Recycle	80%	0.148	13	$252,000 $1,841,000 $50,000	$500,000 $3,682,000	$96,000 $130,000 $42,000	$220,000 $396,000	$177,000 $130,000 $50,000	$261,000 $884,000	17	$21,000	$71,000

[1] More combustion air and better mixing

[2] assumes includes only green liquor clarifier not the white liquor clarifier or lime mud washer clarifier vent

[3] lime mud precoat filter

Annualized cost includes operating and maintenance cost and capital cost distributed over 10 years

Table 3.19

Maximum GLC at Rainy River Forest Products

SOURCE	REPORTED GLC				PREDICTED GLC WITH SOURCE CONTROL								
	Concentration at Property Line ($\mu g/m^3$) (July 1989)[1]	Concentration at 120 m ($\mu g/m^3$) (July 1989)[1]	Concentration at Property Line ($\mu g/m^3$) (Dec. 1991)[2]	Concentration at 500 m ($\mu g/m^3$) (Dec. 1991)[2]	Concentration at Property Line CO#1[3] ($\mu g/m^3$)	Concentration at 500 m CO#1[3] ($\mu g/m^3$)	Annualized Cost Minimum CO#1[3] ($CAN 1994/y	Concentration at Property Line CO#2 ($\mu g/m^3$)	Concentration at 500 m CO#2 ($\mu g/m^3$)	Annualized Cost Minimum CO#2 ($CAN 1994/y)	Concentration at Property Line CO#3 ($\mu g/m^3$)	Concentration at 500 m CO#3 ($\mu g/m^3$)	Annualized Cost Minimum CO#3 ($CAN 1994/y)
Smelt Tank	31.69	22.6	6.52	2.49	1.63	0.62	$293,000	1.63	0.62	$515,000	1.63	0.62	$515,000
Tall Oil Plant Scrubber	3.45	2.02	0.69	0.16	0.69	0.16		0.69	0.16		0.69	0.16	
Effluent Pump House	2.52	1.14	30.28	3.27	10.60	1.14	$153,000	1.27	0.14	$4,552,000	1.27	0.14	$4,552,000
Bleach Plant Scrubber[4]	1.7	1.11	3.4	0.94	0.00	0.00	[4]	0.00	0.00	[4]	0.00	0.00	[4]
Lime Kiln	0.9	6.51	0.6	1.91	0.60	1.91		0.60	1.91		0.60	1.91	
Strong Black Liquor Tank[5]	0.74	0.47	0.61	0.15	0.00	0.00	[5]	0.00	0.00	[5]	0.00	0.00	[5]
Weak Black Liquor Tank[5]	0.28	0.17	0.25	0.06	0.00	0.00	[5]	0.00	0.00	[5]	0.00	0.00	[5]
Brownstock Washer	0.6	0.39	4.4	1.39	0.26	0.08	$490,000	0.00	1.39	$380,000	0.88	0.28	$908,000
Clarifier Vents	-	-	5.25	0.71	0.32	0.04	$490,000	0.00	0.71	$380,000	1.31	0.18	$177,000
Total	42	34	52	11	14	4.0	$1,426,000	4.2	4.9	$5,827,000	6.4	3.3	$6,152,000

[1] March 1990 Report (Appendix B)

[2] February 1992 Report (Appendix B)

[3] Concentrations calculated based on December 1991 results

[4] Included in brownstock washer cost

[5] Combined with smelt dissolving tank vent gases

Source	CO#1			CO#2			CO#3		
	Control	Reduction	Annualized Cost	Control	Reduction	Annualized Cost	Control	Reduction	Annualized Cost
Smelt Tank	switch to caustic	75%	$293,000	new scrubber with caustic	75%	$515,000	new scrubber with caustic	75%	$515,000
Tall Oil Plant Scrubber	none			none			none		
Effluent Pump House	scrubber	65%	$153,000	steam stripper and scrubber	96%	$4,552,000	steam stripper and scrubber	96%	$4,552,000
Bleach Plant Scrubber[4]	none			none			none		
Lime Kiln	none			none			none		
Strong Black Liquor Tank[5]	none			none			none		
Weak Black Liquor Tank[5]	none			none			none		
Brownstock Washer	incinerate in recovery boiler	94%	$490,000	vent from recovery boiler stack	0%	$380,000	new scrubber	80%	$908,000
Clarifier Vents	incinerate in recovery boiler	94%	$80,000	vent from recovery boiler stack	0%	$380,000	new scrubber	75%	$177,000

Annualized cost includes operating and maintenance costs and capital cost distributed over 10 years

Table 3.20

Maximum GLC at Domtar Packaging

Source	Reported Concentrations		Predicted GLC with Source Control											
	Concentration at Property Line ($\mu g/m^3$) (Dec. 1989)	Concentration at 900 m ($\mu g/m^3$) (Dec. 1989)	Concentration at Property Line CO#1 ($\mu g/m^3$)	Concentration at 900 m CO#1 ($\mu g/m^3$)	Annualized Cost Minimum CO#1 ($CAN 1994/y	Annualized Cost Maximum CO#1 ($CAN 1994/y	Concentration at Property Line CO#2 ($\mu g/m^3$)	Concentration at 900 m CO#2 ($\mu g/m^3$)	Annualized Cost Minimum CO#2 ($CAN 1994/y)	Annualized Cost Maximum CO#2 ($CAN 1994/y)	Concentration at Property Line CO#3 ($\mu g/m^3$)	Concentration at 900 m CO#3 ($\mu g/m^3$)	Annualized Cost Minimum CO#3 ($CAN 1994/y)	Annualized Cost Maximum CO#3 ($CAN 1994/y)
Smelt Tank	15.9	6.8	1.6	0.7	$293,000		1.6	0.7	$293,000		1.6	0.7	$293,000	
Brownstock Washer	15.17	6.1	0.9	0.4	$490,000	$1,312,000	0.9	0.4	$3,206,000		0.0	12.0	$380,000	
Turpentine and Causticizing	5.3	1.5	1.3	0.4	$363,000		0.32	0.09	$3,206,000		0.0	0.97	$380,000	
Lime Kiln and Recovery Furnace	0.8	11.4	0.2	2.3	$375,000	$1,195,000	0.16	2.3	$375,000	$1,195,000	0.16	2.3	$375,000	$1,195,000
Total	37.2	25.8	4.0	3.7	$1,521,000	$3,163,000	3.0	3.4	$7,080,000	$7,900,000	1.8	15.9	$1,428,000	$2,248,000

Source	CO#1			CO#2			CO#3		
	Control	Reduction	Annualized Cost	Control	Reduction	Annualized Cost	Control	Reduction	Annualized Cost
Smelt Tank	switch to caustic in scrubber	90%	$293,000	switch to caustic in scrubber	90%	$293,000	switch to caustic in scrubber	90%	$293,000
Brownstock Washer	incinerate in recovery boiler	94%	$490,000-$1,312,000	incinerate in incinerator	94%	$3,206,000	vent from recovery stack	0%	$380,000
Turpentine and Causticizing	new scrubber	75%	$363,000	incinerate in incinerator	94%	$3,206,000	vent from recovery stack	0%	$380,000
Lime Kiln and Recovery Furnace	improved lime mud washing [1]	80%	$357,000-$1,195,000	improved lime mud washing [1]	80%	$357,000-$1,195,000	improved lime mud washing [1]	80%	$357,000-$1,195,000

[1] Includes lime kiln control package, new lime mud filter and lime mud recycle

Annualized cost includes operating and maintenance costs and capital cost distributed over 10 years

Generally, the costs presented here do not allow for the fact that some of the controls could be combined for a cost savings.

3.5.11 Rainy River Forest Products Inc.

The O.Reg. 346 dispersion estimates at Rainy River are shown in Table 3.19.

It is not known whether the dispersion modelling from different years was conducted in the same way and is, therefore, directly comparable.

The modelling shows that the major contributors of TRS to the maximum GLC (based on the most recent data) are the effluent pump house and smelt dissolving tank (although this is not consistent from year to year). Rainy River has already identified the effluent pump house as a major source and is planning to install a scrubber (CO #1 - Table 3.19). The TRS removal efficiency would be limited because the TRS in the vent gas has substantial dimethyl sulphide and dimethyl disulphide components. This should reduce the contribution to the GLC from this source by approximately 65% (from 30.28 $\mu g/m^3$ to approximately 10.6 $\mu g/m^3$ at the property line). Rainy River estimated the capital cost for installation of the scrubber at approximately $400,000 (Table 3.10 - estimated by Rainy River) ($414,000 $CAN 1994). This cost was annualized (according to the methodology outlined in section 3.5.10) to a cost of approximately $153,000/year (see Tables 3.13 and 3.16).

Rainy River is also planning to install a steam stripper (CO #2 - Table 3.19) which will reduce the TRS in the process condensate. This could reduce emissions from the effluent pumphouse by up to 88% (reported efficiency for a steam stripper). The combination of both the steam stripper and the scrubber, could reduce the contribution of this source to the GLC at the property line to 1.3 $\mu g/m^3$. The capital cost for a steam stripper is approximately $5,200,000 (as reported by Rainy River, Table 3.10) ($5,383,000 $CAN 1994). The annualized cost for a steam stripper was determined to be approximately $4,399,000/year (including the cost of the steam).

The smelt dissolving tank also contributes to the maximum GLC (6.25 $\mu g/m^3$ at the property line). Rainy River currently has a scrubber demister system which uses water as the scrubbing liquid. Switching to caustic could reduce their emissions to 5 ppm at the stack exit (a reduction of 75%) (CO #1, Table 3.19). The annualized cost for this option is $293,000/year. If this

change is not possible with the current scrubber system, a new scrubber may be necessary. This would reduce the contribution from this source to the GLC at the property line to approximately 1.63 $\mu g/m^3$. The capital cost for this modification is approximately $1,600,000 ($1,656,000 $CAN 1994) with an annualized cost of $515,000/year.

The next largest contributors to the maximum GLC at the property line are the clarifier[5] vents. The emissions from this source could potentially be collected and incinerated in the recovery boiler reducing the emissions by 94% (CO #1). The remaining emissions would be released from the recovery boiler stack. The annualized cost would be in the order of $80,000/year. Installation of a new scrubber for an annualized cost of approximately $177,000/year (CO #3) would reduce emissions by approximately 75%.

Similarly, the emissions from the brownstock washers and bleach plant scrubber could be collected and incinerated in the recovery boiler (CO #1 - Table 3.19) for a total annualized cost in the order of $490,000/year reducing the maximum GLC contribution from these sources to 0 $\mu g/m^3$ as the emissions would be released from the recovery boiler stack. The recovery boiler at Rainy River was designed to accept vent gases as incineration air. However, due to previous operational problems, this capability has been removed.

Alternatively, the brownstock washers, bleach plant scrubber and the clarifier vents could be routed to the recovery stack (CO #2 - Table 3.19) for greater dispersion for an annualized cost of approximately $380,000/year per source. The brownstock washers and the bleach plant scrubber could probably be collected together, for a total annualized cost of $760,000/y. This option will not reduce the overall mass of TRS emissions, but may reduce the GLCs.

Brownstock washer gases could also be collected together with the bleach plant vent gases and routed to a new scrubber. The chlorine and chloride dioxide in the bleach plant gases will oxidize the TRS compounds. The annualized cost for this option (CO #3) is approximately $908,000/year and will reduce emissions by approximately 80%.

Therefore to reduce the GLC at the property line from 52.0 $\mu g/m^3$ to approximately 4.2 $\mu g/m^3$, the annualized cost is estimated to be in the order of $5,827,000/year (Table 3.19). This cost

[5] It was not clear from the reports which clarifier vents are presented. Therefore, a recaustucizer clarifier vent has been assumed.

includes installing a new scrubber on the smelt dissolving tank, a steam stripper, a new scrubber on the effluent pump house vent and ducting brownstock washer and clarifier vent emissions to the recovery boiler stack.

Table 3.16 outlines the different control options which could be applied to the different sources at Rainy River and the range of annualized costs for each option. The cost effectiveness of each option is also calculated. The most cost effective source for control to remove TRS emissions is the smelt dissolving tank. The least cost effective sources for control are the weak black liquor tank and the brownstock washer stack.

Because of Rainy River's proximity to the property line, even their small emission sources (clarifier vents) can be significant contributors to the GLC of TRS.

3.5.12 Malette Pulp and Power

O.Reg. 346 modelling was conducted by Concord Environmental (February 1993) for this plant. The contribution from each source to the maximum GLC (near eastern property boundary) is as follows:

1)	Brownstock washers	0 $\mu g/m^3$
2)	Old recovery boiler	5 $\mu g/m^3$
3)	Smelt dissolving tank	1 $\mu g/m^3$
4)	New recovery boiler	0 $\mu g/m^3$
5)	Lime kiln with ESP	0 $\mu g/m^3$

See Appendix B for details.

According to the O.Reg 346 modelling results presented above, the old recovery boiler is the major source of TRS contributing to the maximum GLC. This recovery boiler is the old direct contact type which does not have a black liquor oxidation system. One way to reduce TRS is to install a black liquor oxidation system. This could potentially reduce the maximum GLC by approximately 80% (from 5 $\mu g/m^3$ to 1 $\mu g/m^3$). The Malette pulp mill is relatively small (411 ADt pulp/day); and the estimated annualized cost to install a black liquor oxidation system is $785,000/year (see Tables 3.14 and 3.17). Conversion to a low odour boiler would incur

annualized costs of approximately $6,000,000 to $13,000,000/year, though both of these cost estimates would be offset somewhat by the savings realized in not operating the scrubber. Table 3.13 estimates the operating and maintenance costs for a recovery boiler scrubber to be approximately $1,073,000 - $1,337,000/year.

Table 3.17 presents the different control options which could be applied to the various sources of TRS and estimates their cost effectiveness.

3.5.13 Domtar Packaging

The estimated maximum contribution to the TRS GLC at the property line from different sources at the property line based on the December 1988 report (Appendix B) are presented in Table 3.20.

The O.Reg. 346 modelling of the Domtar Packaging Mill shows that the major sources contributing to the GLC at the property line are the smelt dissolving tank, the brownstock washers and the turpentine and causticizing vents. At approximately 900 m from the property line, the lime kiln and recovery furnace are the largest contributors.

In general, there are two possible control options for control of vent sources:

1) collection of vent sources and incineration in the recovery boiler; and

2) collection and venting through the recovery boiler stack.

Domtar (1995) believes that neither of these control options are technically feasible. The vent gas sources are wet and corrosive and spread throughout the mill, far from the recovery boiler. Domtar is concerned about the likelihood of corrosion in the ducts resulting in H_2S leaks into operating areas or creating an explosion hazard. As discussed in Section 3.5.7, the ductwork proposed for these control options is to be constructed from stainless steel and is therefore resistant to corrosion by water and sulphur compounds. Also included in these costs are fans, knock-out drum(s), flame arrestor(s), rupture discs, supports and insulation. These measures should minimize the risk of H_2S leaks and explosion hazards. However, this facility would have to be examined in much greater detail to determine whether or not these control options are

economically feasible. It may be necessary to install a dedicated incinerator if the vent gases cannot be accommodated in an existing combustion device.

The smelt dissolving tank contributes approximately 15.9 $\mu g/m^3$ TRS to the GLC at the property line. The emissions from this source are currently controlled by using weak wash in the venturi scrubber. Using a caustic solution (CO #1 - Table 3.20) in the scrubber could reduce the stack exit concentration by 90% to 5 ppm TRS, reducing the property line concentration to approximately 1.6 $\mu g/m^3$ TRS. Domtar (1995) believes that this modification would be extremely costly and is concerned that it would upset the recausticizing water balance. The amount of caustic make-up to the recirculating system would be limited -- about 4 U.S. gpm of 5% caustic. The associated amount of water is so small that the impact on the recausticizing water balance would be minimal. The cost of the caustic would be between zero and $100,000 per year depending on whether or not the caustic could be used as make-up to the liquor cycle. The capital cost for this modification would be approximately $200,000 (Table 3.12), with an annualized cost of $293,000/year (Table 3.18; CO#1 - Table 3.20)

Controlling emissions from the brownstock washers (0.102 g/s TRS) involves collecting the vent gases and incinerating them. If it is possible to incinerate these gases in the recovery or power boiler, the estimated annualized cost (Table 3.18) is $490,000 to $1,312,000/year (CO #1 - Table 2.20). The foregoing control method would reduce emissions by 94% (0.0006 g/s) and the remaining gas would be released from the recovery or power boiler stack. If necessary, the brownstock washer gases could be incinerated in a stand alone incinerator. The annualized cost for this option is approximately $3,206,000/y (CO #2). Domtar (1995) has brought brownstock pressure washers on-line. These have not proven to be reliable. TRS losses at the pressure washers are low, but the TRS compounds remain intact and are released from tank vents and at the paper machines. Because the emissions are spread out, collection and incineration of the compounds will be less efficient and consequently more costly.

Control of emissions from the turpentine and causticizing vents will involve collecting the vent gases and installing a scrubber or routing them to an existing incineration device or stand alone incinerator. Domtar (1995) does not believe that including the turpentine vent in the NCG system is a practical option and that gases from the causticizer are too wet to burn safely. They feel that there will not be enough discretionary air to properly operate the lime kiln and it could pose a major explosion hazard. Domtar is concerned that the gas flow rates from the turpentine

system and the causticizing vents would enable a scrubber to perform efficiently enough to justify the costs involved. However, this could be addressed in the design of a system. Provision of a steam ejector would provide a positive flow for these gases through the scrubber system. The estimated annualized cost for scrubbers (75% control) (CO #1 - Table 3.20) would be approximately $121,000/year/scrubber ($363,000 total) (Table 3.18) and the annualized cost for collection and incineration in a stand alone incinerator (CO #2 - Table 3.20) (94% control) would be approximately $3,206,000/year (Table 3.18). The brownstock washer gases could also be incinerated in a stand alone incinerator for a similar cost (CO #2 - Table 3.20).

Alternatively, the brownstock washer emissions, turpentine vent emissions and causticizer vent emissions could be collected and vented from a tall stack (i.e. recovery boiler) (CO #3 - Table 3.20) which will provide greater dispersion. At this facility, however, the emissions from both the recovery stack and lime kiln stack are already relatively high (Table 3.9), and increasing the emissions from these stacks could create problems downwind of the facility. The annualized cost for this option (CO #3) is $380,000/year per source (Table 3.20). Since these sources are located at considerable distances from the recovery boiler stack, Domtar questions whether this solution is feasible.

It may be possible to reduce emissions from the recovery boiler to 5 ppmv (corrected to 8% O_2) (U.S. EPA reference O_2 concentrations) with improvements to the combustion air supply and liquor spraying. Improvements to the combustion air supply might include provision of more excess air and changes to the manner in which air is added to the furnace, so that gas mixing is improved. For example, partially interlaced secondary air jets might be used and two-wall primary air might be implemented. Changes to the manner in which black liquor is sprayed into the furnace may also be beneficial. This could provide a reduction of approximately 60% in TRS emissions.

Emissions from the lime kiln are very high (Table 3.9). This is likely due to poor lime mud washing. Improved lime mud washing and lime kiln combustion controls (discussed in Section 3.2.10) could reduce emissions by 80% to 0.15 g/s TRS. A small improvement in lime mud washing could be obtained cost-effectively by installing lime mud recycle (annualized cost $50,000/year). A larger improvement in lime mud washing could be obtained by replacing the existing lime mud filter with a much larger unit (annualized cost $130,000 to $884,000/year). The existing filter could be reused as a dregs filter, under another project. A combustion control

package for the lime kiln would help to manage kiln combustion air to minimize TRS emissions (annualized cost $177,000 to $261,000/year). The total annualized cost for all of these controls ranges from approximately $375,000 to $1,195,000/year (Table 3.18) (CO #1 - Table 2.20). Domtar (1995) believes that the costs for these options would be considerably higher.

In the dispersion modelling results presented (Domtar 1989), the TRS contribution from the lime kiln and recovery boiler are grouped together. To estimate the reduction which could be applied to the grouped sources, the reduction at the lime kiln and at the recovery boiler have been averaged.

Assuming a 60% TRS reduction in recovery boiler emissions and an 80% TRS reduction in lime kiln emissions, the overall mass emission reduction from the two sources is approximately 70%. Therefore, the downwind TRS contribution of the recovery boiler and the lime kiln to the GLC at 900 m from the property line could be reduced from 11.4 $\mu g/m^3$ to 3.4 $\mu g/m^3$ and could be reduced from 0.8 $\mu g/m^3$ to 0.2 $\mu g/m^3$ at the property line.

The total annualized cost to control TRS emissions and to reduce the GLC from 37.2 $\mu g/m^3$ at the property line to approximately 4.0 $\mu g/m^3$ would be approximately $1,521,000 to $3,163,000/year (Table 3.20). This cost includes switching to caustic scrubbing liquid in the smelt dissolving tank scrubber, incinerating brownstock washer gases in the recovery boiler, a new scrubber on the turpentine and causticizing vents and improved lime mud washing. Installing a dedicated incinerator to accommodate the brownstock washer and turpentine and causticizing vent gases will result in an annualized cost of approximately $7,080,000 - $7,790,000/year.

At Red Rock, it may be necessary to install a dedicated incinerator to treat the brownstock washer emissions, the turpentine vent emissions and the causticizer vent emissions, if they cannot be accommodated in the recovery boiler or power boiler.

4.0 IRON AND STEEL INDUSTRY

4.1 SOURCES

TRS emissions in the iron and steel industry have not been a priority in the past. The main contaminant of concern has been Total Suspended Particulate (TSP) and sulphur dioxide (SO_2). Consequently there is very little information available on TRS emissions and control alternatives for the iron and steel industry.

Potential sources of TRS in the iron and steel industry are (Cocchiarella 1994):

1) iron slag quenching operations;
2) coke oven and by-products plant;
3) coke quenching; and
4) quenching of steel slag (possible at low levels: steel slag has 0.05% S, iron slag has 1.5% S).

Coke used for metallurgical processing is formed from heating high grade bituminous coal in a coke oven without oxygen. This process drives off the volatile compounds present in the coal. Coke provides three functions which are necessary for the blast furnace method of iron production from iron ore (AWMA 1992):

1) Coke is a porous material which provides support for the iron ore pellets and limestone in the blast furnace and allows the hot blast to blow through the furnace;

2) Coke provides the fuel which supplies the heat for the reducing atmosphere required to refine the ore into iron; and

3) Coke acts as a chemical reductant which converts oxides in iron ore to metallic iron.

The steel industry has been investigating different methods of reducing the need for coke in blast furnaces. There has been some success replacing some of the coke with other fuels, however,

coke is still necessary as a support and as a chemical reductant. Improving the quality of the coke (particularly the strength) could further reduce the use of coke in the blast furnace.

Steel is generally produced in a basic oxygen furnace or an electric arc furnace. The carbon and silicon in molten iron is oxidized with oxygen which removes these products, and lime is added to provide the desired basicity in the slag. The steel process is illustrated in Figure 4.1.

Because there is very little information available on TRS (99% H_2S - Manka 1975) emissions from the iron and steel industry, the following discussion will focus on emissions from coke oven batteries and iron slag quenching. Other sources may contribute small quantities of TRS, however, there is very little information available in published literature. As described by Cocchiarella (1994), emissions from coke pushing and steel slag quenching may also occur, however due to the lack of quantitative information on emissions from these sources, they will not be discussed further.

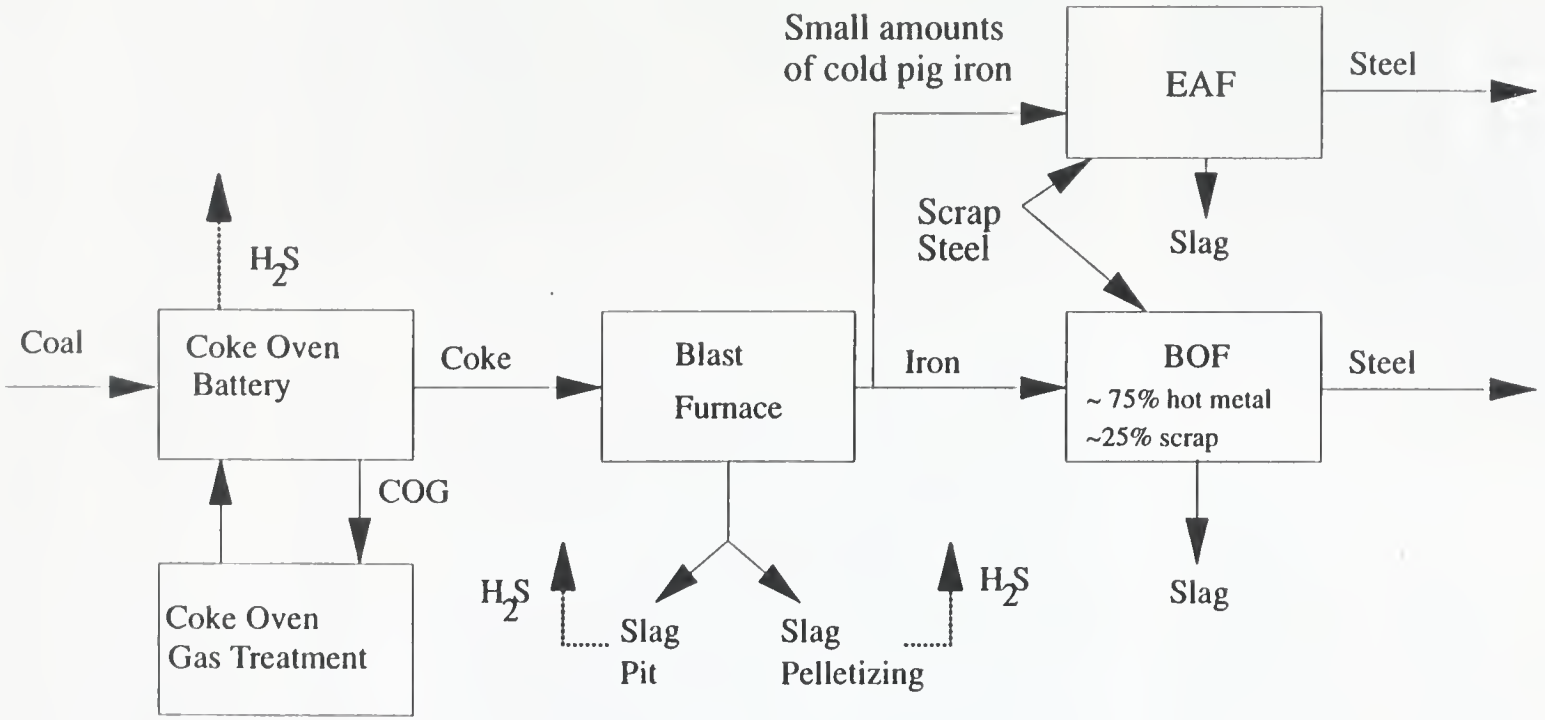
4.1.1 Coke Oven Batteries

Coke oven batteries are made up of 25 to 100 coke ovens (65 average) adjacent to each other. The ovens are charged (fed with coal) one at a time by a larry car. The charged coal is levelled with a levelling bar to ensure uniform distribution for even coking and good gas flow. Once the coal has been fully coked (approximately 12-24 hours), a pusher ram (from the pusher side of the oven) pushes the coke out of the coke side of the oven. The coke (known as metallurgical coke) is then quenched before it is used in the iron blast furnace.

There are two types of batteries currently being used in the metallurgical industry, the slot-oven by-product battery and the non-recovery battery. The volatile compounds driven off the coal are collected in the slot-oven by-product battery. These gases are refined to produce clean coke oven gas (COG), tar, sulphur, ammonium sulphate, light oil and anhydrous ammonia in the coal chemical plant. Up to 40% of the clean COG produced is used to heat the battery.

In the non-recovery battery, the volatile compounds given off from the coal are combusted in the oven to provide the heat required for carbonization. This type of battery is not currently widely used, however, it may be an alternative when present coke plants need to be reconstructed as it eliminates the need for the associated by-products plant.

Figure 4.1
Iron and Steel Industry



Coke oven emissions are measured by visible emissions estimating procedures. They are emissions of COG which are visible because the benzene soluble organics (BSO) in the COG condenses and forms a particulate. Contaminant mass emissions from coke oven leaks have not been determined (based on the documents reviewed). Since the visible emissions are COG, the relative proportion of COG constituents can be used as a rough estimate of mass emissions. The estimating method is not an accurate correlation and emission estimates reported in literature may vary by an order of magnitude (U.S. EPA 1987). However, because there is no better data, this approach will be used for mass emission estimates of H_2S for this study. Table 4.1 gives the relative proportion of COG constituents used to estimate H_2S emissions for this study.

The rates of emissions from doors change over the coking cycle as small gaps are plugged with tar. Emissions from lids and offtakes vary depending on the application of luting (worker practice, pressure fluctuations and gap size), therefore H_2S would also be controlled. The concentrations of pollutants will also vary over the coking cycle and variations due to coal type and battery conditions will also affect the pollutant concentrations. Mass emission rates are generally not considered practical for these reasons. Instead, visible emission estimates are used.

Visible emissions give a good measure of emission control. If a point of emission is controlled sufficiently to eliminate visible emissions, then all emissions including the carcinogens are controlled effectively (U.S. EPA 1987). In the United States, standard techniques have been developed to asses coke oven emission control. For topside leaks (charging ports and lids) this involves counting the total number of visible leaks. The rate of leaking lids is expressed as a percentage of this number of visible leaks and the total number of potential leaks. Each charging port and each stand pipe is considered to be a potential source of one leak (U.S. EPA 1987). The rate of leaks is reported as percent leaking lids (PLL) and percent leaking offtakes (PLO).

Coke oven door leaks are measured in a similar way and are reported as percent leaking doors (PLD).

Charging emissions are based on the number of seconds of visible emissions during the charge and are reported in seconds per charge (s/charge).

The U.S. regulates based on visible emissions. The 1990 Amendments to the Clean Air Act established the requirement for the development of regulations governing coke oven emissions.

Standards were based on maximum achievable control technology (MACT). For existing sources these standards are no less stringent than the best performing 12% of existing sources. The standards for new sources cannot be less stringent than the limit achieved in practice by the best controlled existing source. The proposed visible emission standards are presented in Table 4.2. The dates shown in Table 4.2 represent target dates for the proposed limits.

In Ontario, the regulations are based on ground level concentration. For this study, it is therefore necessary to estimate mass emission rates for coke oven batteries. The Air and Waste Management Association (1992) provides a breakdown (relative proportion) of COG constituents (Table 4.1).

The U.S. EPA (1987) provides an estimate of typical BSO emissions for charging, leaking doors, lids and offtakes (this data was compiled with the assistance of the American Iron and Steel Institute). These values were used to estimate approximate emission factors for a "typical" poorly controlled battery (Table 4.1). The instantaneous emissions rates for the different COG constituents due to charging, door, lid and off-take leaks for a "typical" poorly controlled battery are given in Table 4.3. A "typical" battery is defined by the U.S. EPA as one with 62 ovens, 16.3 Mg coal/oven and an 18-hour cycle time.

Most coke oven batteries in the U.S. offer much better control than as described for the poorly controlled battery (3 minutes charging emissions; 30 PLD; 20 PLL; 20 PLO). U.S. EPA (1987) provides visible emission data collected from coke ovens throughout the U.S. (Appendix D). The average control for: charging is 7.5 g/charge; doors is 4.5 PLD; lids is 0.44; offtakes 1.6. These average control levels are below the MACT units of 12 s/charge, 5.5 PLD, 0.6% PLL and 3% PLO.

Table 4.1

Typical Coke Oven Gas Emissions for a Poorly Controlled Battery[2]

Material	Relative Proportion of Chemical (g/h/leak)[1]	Charging Emissions[2] (kg/Mg coal)	Door Emissions[2] (kg/Mg coal)	Lid Emissions[2] (kg/Mg coal)	Offtake Emissions[2] (kg/Mg coal)
Acetylene	0.01	0.003	0.007	0.0001	0.0001
Ammonia	0.16	0.040	0.104	0.0016	0.0016
Benzene	0.34	0.085	0.221	0.0034	0.0034
Butane	0.02	0.005	0.013	0.0002	0.0002
Butylene	0.07	0.018	0.046	0.0007	0.0007
Carbon Dioxide	0.47	0.118	0.306	0.0047	0.0047
Carbon Monoxide	1.53	0.383	0.995	0.0153	0.0153
Ethane	0.29	0.073	0.189	0.0029	0.0029
Ethylene	0.50	0.125	0.325	0.0050	0.0050
Hydrogen	0.80	0.200	0.520	0.0080	0.0080
Hydrogen Cyanide	0.04	0.010	0.026	0.0004	0.0004
Hydrogen Sulphide	0.24	0.060	0.156	0.0024	0.0024
Methane	3.43	0.858	2.230	0.0343	0.0343
Nitrogen	0.25	0.063	0.163	0.0025	0.0025
Oxygen	0.06	0.015	0.039	0.0006	0.0006
Propane	0.04	0.010	0.026	0.0004	0.0004
Propylene	0.09	0.023	0.059	0.0009	0.0009
Toluene	0.03	0.008	0.020	0.0003	0.0003
Xylene	0.02	0.005	0.013	0.0002	0.0002
Benzene Soluble Organics	0.20	0.050	0.130	0.0020	0.0020

NOTES

[1] AWMA Air Pollution Engineering Manual - for 30 PLD

[2] U.S.EPA 1987 describes a poorly controlled battery as the following:

- 3 minutes uncontrolled charging emissions
- 30% leaking doors
- 20% leaking lids or offtakes
- 62 ovens with 2 doors each
- 16.3 Mg coal/oven
- 18 hour cycle time

Table 4.2
U.S. EPA PROPOSED COKE OVEN EMISSION STANDARDS

Emission Points	MACT track limits		LAER extension track limits		
	12/31/95	01/01/03	11/15/93	01/01/98	01/01/10
Tall doors, PLD	6.0	5.5	7.0	4.3	4.0
Foundry doors, PLD	5.5	5.0	7.0	4.3	4.0
All other doors, PLD	5.5	5.0	7.0	3.8	3.3
Lids, PLL	0.6	0.6	0.83	0.4	0.4
Offtakes, PLO	3.0	3.0	4.2	2.5	2.5
Charging, s/charge	12	12	12	12	12

MACT	=	Maximum Achievable Control Technology
LAER	=	Lowest Achievable Emissions Rate
PLD	=	Percent leaking doors;
PLL	=	Percent leaking lids;
PLO	=	Percent leaking offtakes
s/charge	=	Seconds of emissions/charge

COG emission rates from an average battery controlled at the MACT limits are given in Table 4.4. Example calculations are provided in Appendix E. The total H_2S emission rate from all sources is 0.025 g/s/battery (one hour average).

4.1.1.1 By-Product Coke Production

In by-product coke production, coal is charged into the battery through lidded openings above the oven chamber with larry cars and levelled. The coal in the oven is coked (heated to drive off the volatile gases). Approximately 25% (by mass) of the coal charged is volatilized and removed as gas. The volatile gases are collected during the coking process by off-take piping and routed to the collector main and treated in the by-product recovery plant then vented through a stack. The battery is fired with COG, natural gas or blast furnace gas.

Potential emission points from the battery are:

1) pushing emissions
2) charging emissions
3) door emissions
4) topside emissions
5) flue stack emissions

Coke Oven Charging

Though the oven is kept at negative pressure during charging, there will still be some leakage when the oven is charged. Particulate emissions during charging are composed of BSO and coal dust.

U.S. EPA 1987 presents a mathematical model to estimate controlled mass emissions from the uncontrolled emission factor (Allen 1980, as cited in U.S. EPA 1987). Mass emissions are proportional to the square of the time of observed emissions. This model can only be used as a tool to estimate upper bound mass emissions. Figure 4.2 presents the range of H_2S emission rates estimated using the model, for an average battery (62 ovens, 16.3 Mg coal/charge).

Coke Oven Doors, Lids and Off-takes

During the coking cycle, coke ovens are kept at a slightly positive pressure. Therefore, if the seals between doors and jambs and brickwork are not perfect, the raw COG produced will leak from these points. Table 4.1 gives the expected emissions from coke oven door leaks, and leaks from coke oven lids and off-takes (piping assembly). When coke oven lids are open during charging or pushing, the oven is kept at negative pressure, to control emissions.

Allen 1980 (as cited in U.S. EPA 1987) presents a model to estimate mass emissions based on PLD. This model considers the change in emissions over time due to door sealing time, oven pressures, gap sizes and gas characteristics. The model predicts that mass emissions are roughly proportional to the 2.5 power of PLD down to levels of 10 PLD. Below 10 PLD, the model becomes more linear with a PLD exponent of 1.6. Figure 4.3 presents the relationship between H_2S mass emissions and PLD for an average battery.

Table 4.3

Instantaneous Coke Oven Gas Emission Rates for Poorly Controlled Batteries[1]

Material	Charging Emissions (g/s/battery)	Door Emissions (g/s/battery)	Lid Emissions (g/s/battery)	Offtake Emissions (g/s/battery)
Acetylene	0.23	0.10	0.002	0.002
Ammonia	3.62	1.62	0.025	0.025
Benzene	7.70	3.45	0.053	0.053
Butane	0.45	0.20	0.003	0.003
Butylene	1.58	0.71	0.011	0.011
Carbon Dioxide	10.64	4.76	0.073	0.073
Carbon Monoxide	34.64	15.51	0.239	0.239
Ethane	6.57	2.94	0.045	0.045
Ethylene	11.32	5.07	0.078	0.078
Hydrogen	18.11	8.11	0.125	0.125
Hydrogen Cyanide	0.91	0.41	0.006	0.006
Hydrogen Sulphide	5.43	2.43	0.037	0.037
Methane	77.65	34.77	0.535	0.535
Nitrogen	5.66	2.53	0.039	0.039
Oxygen	1.36	0.61	0.009	0.009
Propane	0.91	0.41	0.006	0.006
Propylene	2.04	0.91	0.014	0.014
Toluene	0.68	0.30	0.005	0.005
Xylene	0.45	0.20	0.003	0.003
Benzene Soluble Organics	4.53	2.03	0.031	0.031

NOTES

[1] U.S.EPA 1987 describes a poorly controlled battery as the following:

- 3 minutes uncontrolled charging emissions
- 30% leaking doors
- 20% leaking lids or offtakes
- 62 ovens with 2 doors each
- 16.3 Mg coal/oven
- 18 hour cycle time

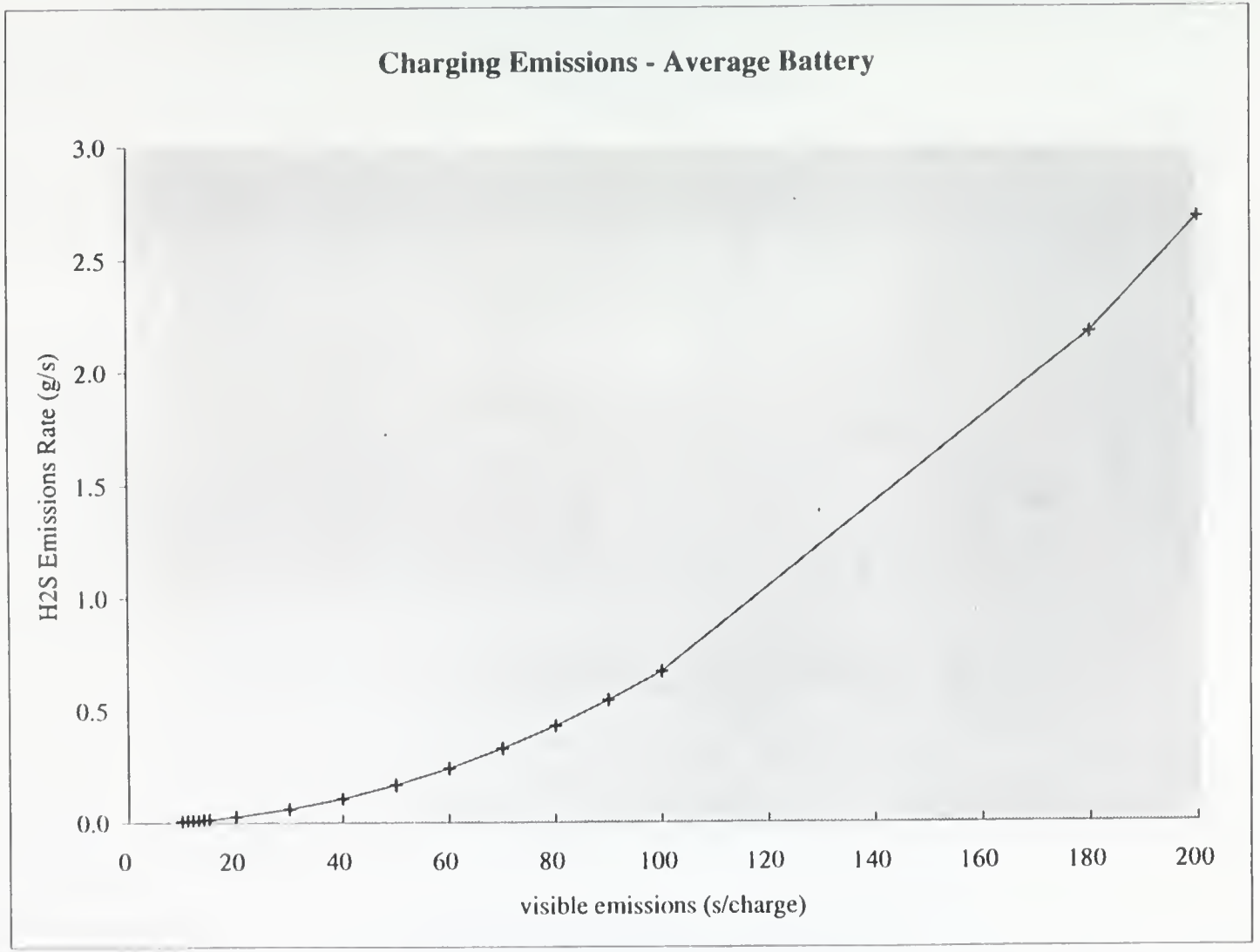
Table 4.4
One Hour Average Coke Oven Gas Emission Rates for a Battery Operating at MACT Limits

Material	Charging Emissions (g/s/battery)	Door Emissions (g/s/battery)	Lid Emissions (g/s/battery)	Offtake Emissions (g/s/battery)
Acetylene	0.0004	0.0003	0.0001	0.0002
Ammonia	0.006	0.005	0.001	0.004
Benzene	0.014	0.010	0.003	0.008
Butane	0.001	0.001	0.0002	0.0005
Butylene	0.003	0.002	0.001	0.002
Carbon Dioxide	0.019	0.014	0.004	0.011
Carbon Monoxide	0.062	0.046	0.012	0.036
Ethane	0.012	0.009	0.002	0.007
Ethylene	0.020	0.015	0.004	0.012
Hydrogen	0.032	0.024	0.006	0.019
Hydrogen Cyanide	0.002	0.001	0.0003	0.001
Hydrogen Sulphide	0.010	0.007	0.002	0.006
Methane	0.138	0.104	0.027	0.080
Nitrogen	0.010	0.008	0.002	0.006
Oxygen	0.002	0.002	0.000	0.001
Propane	0.002	0.001	0.000	0.001
Propylene	0.004	0.003	0.001	0.002
Toluene	0.001	0.001	0.000	0.001
Xylene	0.001	0.001	0.000	0.000
Benzene Soluble Organics	0.008	0.006	0.002	0.005

NOTES
MACT Limits
12 seconds/charge
5.5 percent leaking doors
0.6 percent leaking lids
3.0 percent leaking offtakes

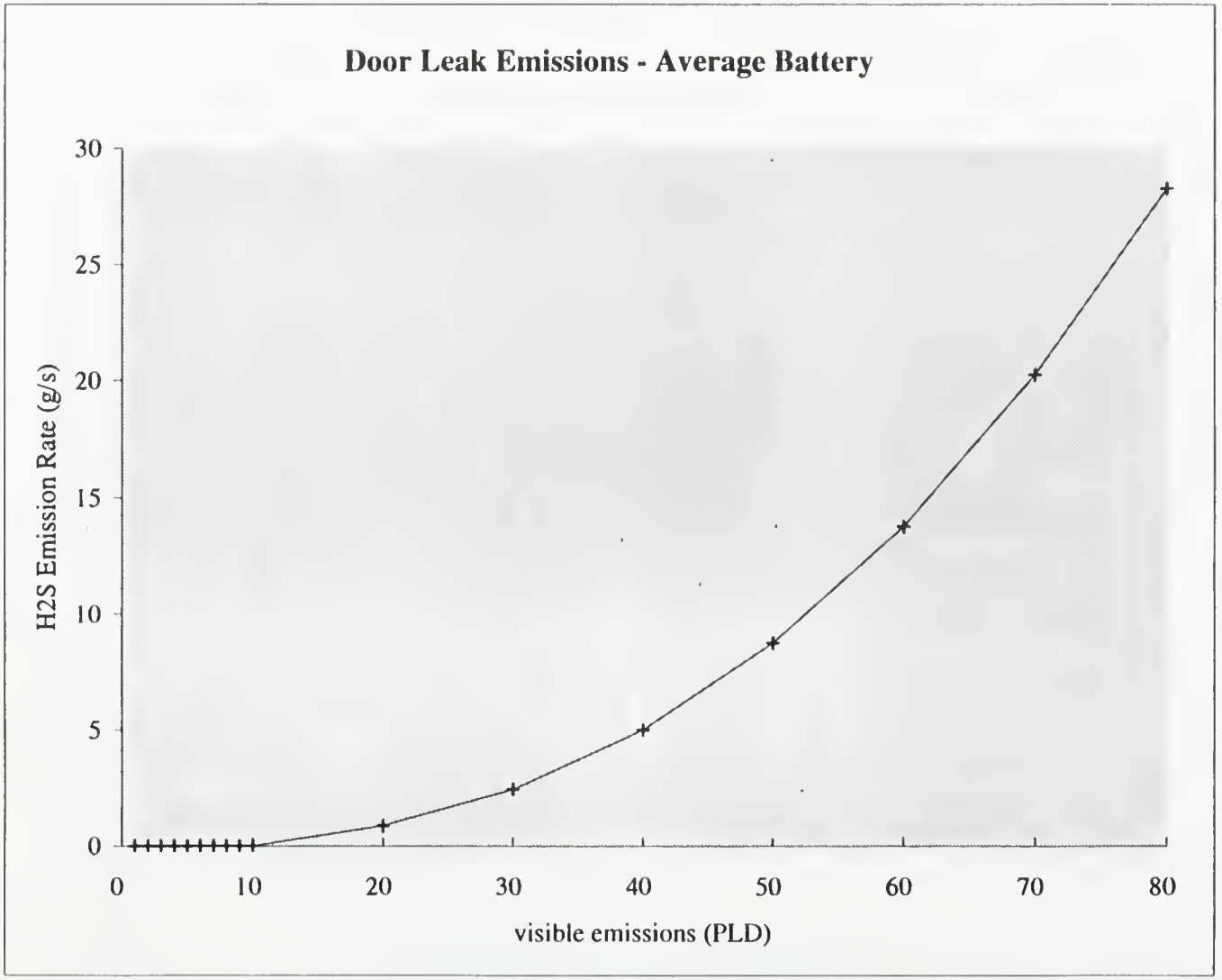
Assumptions
8 charges/hour - charging emissions averaged over the hour
emissions from doors, lids and offtakes are constant with time

Figure 4.2



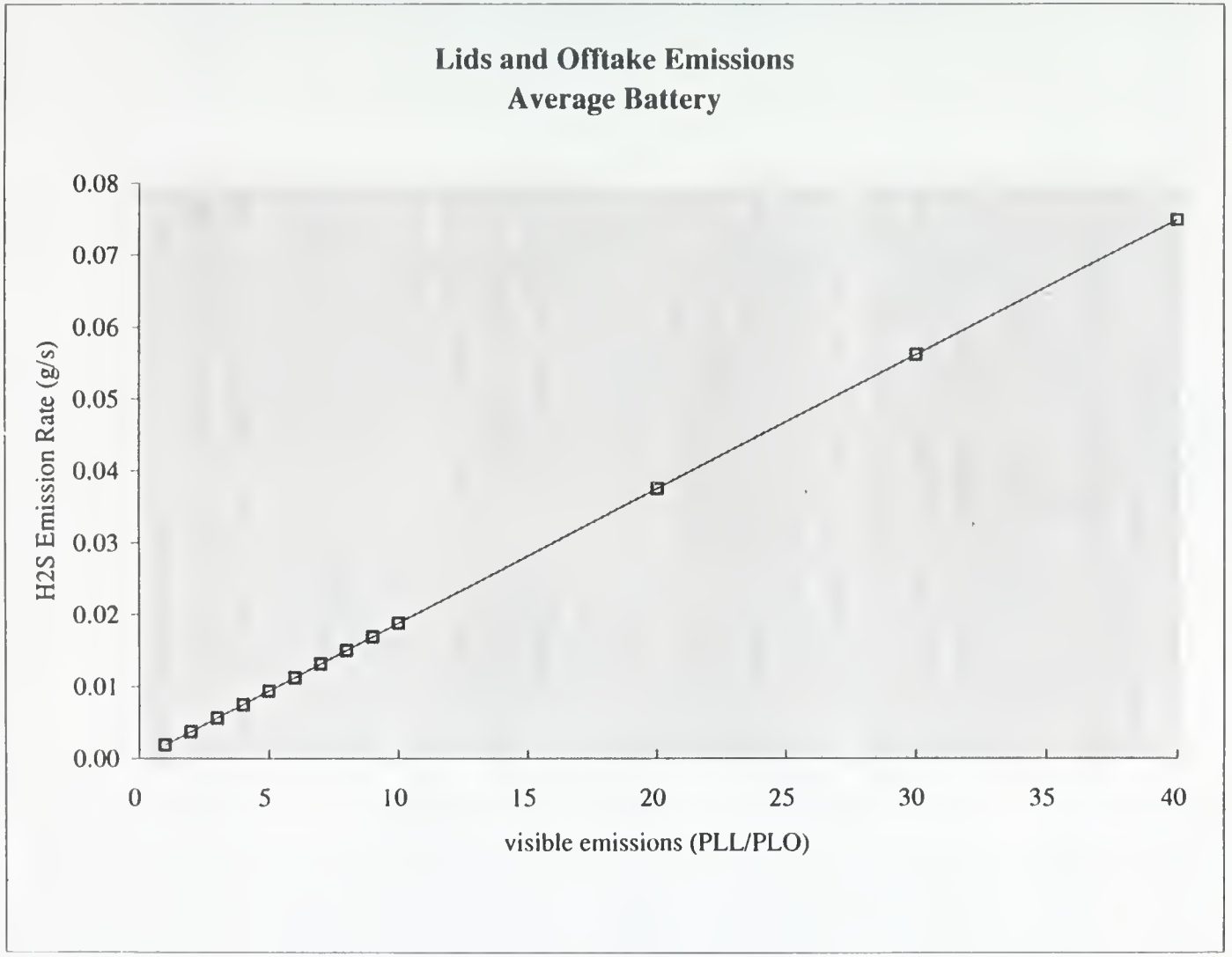
Emissions are estimated for a coke oven battery with 62 ovens, 16.3 Mg coal/oven

Figure 4.3



Emissions are estimated for a coke oven battery with 62 ovens, 16.3 Mg coal/oven

Figure 4.4



Emissions are estimated for a coke oven battery with 62 ovens, 16.3 Mg coal/oven

Based on an emission test conducted at U.S. Steel's Clairton Battery, the U.S. EPA estimated that emissions from a small lid leak would be approximately 0.0033 kg BSO/h and a large lid leak would be approximately 0.021 kg BSO/h (U.S. EPA 1987). Mass emissions from lids were assumed to be linearly proportional to PLL and PLO. The relationship between PLL/PLO and H_2S mass emissions is presented in Figure 4.4.

Coke Oven Pushing

The primary emission is carbon particulate. Emissions during pushing are not usually considered a source of air toxics. The toxics have generally been volatilized and collected. Emission rates from uncontrolled coke pushing have been reported (AWMA 1992), but are not well documented.

If the coal is not completely coked (green coke), the coke may contain volatile matter which will ignite when contacted with air, releasing emissions. TRS mass emissions from this source have not been estimated.

Coke Oven Flue Stack

The combustion products from heating the battery are vented through the flue stack. The stack provides natural draft to the battery combustion system under and around the battery. Coke battery stack emissions are typical of emissions from other combustion sources containing particulate, NO_x and SO_2.

Coke Quenching

Water is sprayed onto the hot coke to reduce the temperature so that it will not burn. The main emission from this process is particulate matter. Emissions from this process are not considered to be hazardous air pollutants (AWMA 1992).

Battery Venting

Raw COG is vented (generally through a flare) when the COG generation rate is greater than can be removed. This generally indicates a breakdown in the exhauster system. The quantity of the emission is dependant on the amount of gas collected by the collection system. Mass emissions

from this source have not been estimated, but Cocchierella (1995) states that visible emissions from this source are low.

Coke By-Product Recovery Plant

COG is collected and cleaned in the coke by-product plant. By-products such as tar, light oil, sulphur, ammonium sulphate, anhydrous ammonia and hydrogen are recovered for sale. The cleaned COG is used as a fuel in the coke ovens and in other processes.

Sulphur is the only by-product which is not readily saleable.

One process stream which may generate sulphur emissions is the "tail gas" from the sulphur recovery plant. In the commonly used Stretford process, hydrogen sulphide is converted into elemental sulphur. However, fugitive emissions could occur at any point in the system. Effective leak detection and repair will minimize these emissions.

The main emission of concern from the by-product recovery plant is benzene. There is little, if any, information available on TRS emissions.

4.1.1.2 Non-Recovery Battery Coke Production

The combustion products driven from the coal in this type of coke production are burned in the chamber above the coal charge, and in the gas pathway through the walls (there are two to six off-take ports in each oven wall) and beneath the oven (the sole flues - these are supplied by the off-take ports).

Coal is charged into the oven either through the lidded holes in the top of the oven or through the oven door by a conveyor. There is a slight negative pressure maintained in the oven at all times because of the natural draft supplied by the stack. This eliminates the door and charging lid leakage associated with by-product coke production. Measurements of emissions during oven charging detected TSP and benzo-α-pyrene. Benzene-soluble organics (BSO) was not detected. Emissions from coke oven and pushing are similar to by-product oven operations. Combustion stack emissions from non-recovery battery coke production do not contain the polycyclic aromatic hydrocarbon typically associated with COG emissions.

4.1.2 Blast Furnace

The blast furnace reduces iron oxide to iron (in the molten form). Coke combustion provides the CO necessary for this reaction and the heat to melt the iron and the impurities (slag). Air (necessary for combustion) is blown into the bottom of the furnace, and gases exit at the top of the furnace. The molten iron and slag are drained (tapping or casting) from the bottom of the furnace, and then separated. The molten iron carries on to the steel making processes. The slag is quenched and is often used in Portland cement production.

Top Gas

Top gas has a fairly low heating value and is sometimes used as a fuel in steel plants. The main components of the top gas are CO and TSP. Trace levels of H_2S and SO_2 may be detected.

Tapping (Casting) Liquid Iron

The slag/metal mixture exits from the furnace into a trough. The slag (containing high levels of CaS) floats to the top, and is skimmed from the molten iron. The molten iron is drained into a torpedo car for delivery to oxygen steel making facilities. The slag is drained into a pit or slag pot where it is quenched.

Iron oxide fume is released either by direct vaporization or by CO bursting bubbles at the metal/atmosphere interface. Emissions generally contain sulphur dioxide and CO.

Slag Processing

Slag is discharged into a pit/pot or granulated/pelletized. The quenched/air cooled pit slag is formed by cooling hot slag with a limited amount of water in large pits. Pelletized slag is produced by imparting a centrifugal force on the slag stream by a rotating drum or plate and water jets. The temperature at the time of discharge is approximately 1,500°F, therefore, it must be cooled before it can be excavated safely. This is achieved with water quenching which generates high levels of H_2S because approximately 95% of the sulphur in the coke fed to the blast furnace is contained within the slag (U.S. EPA 1987). Air cooled pit slag is a higher

density material and is used as aggregate in roads and cement. The pelletized material has many voids and is lower in density making it useful for light weight concrete blocks.

H_2S emissions from slag operations are not well documented and measured values are variable. This is due to many factors including the process, the quality of the slag (dependant on the quality of the coke feed) and the method of H_2S measurement. Both slag pits and pelletizers are located in the open so estimating a mass emission rate is difficult. Table 4.5 shows the variability in emissions measured at Stelco's Hilton Works and at Dofasco.

Table 4.5
MEASURED H_2S EMISSIONS FROM SLAG OPERATIONS

Slag Processing	Location	H_2S Emissions (ppm)	H_2S Emission Rate (g/s)	Source
Pit quenching	Dofasco	22	18.5	AWMA 1993 (adapted from Klag and Iaboni 1987)
Pit quenching	Dofasco	48.8	13	MOE 1986 memorandum
Pit quenching	Stelco	3.04	7.3	IMET 1987
Pit quenching	Stelco	13.6	18	MOE 1986 memorandum
Expanding (pelletizing)	Dofasco	10	10.5	AWMA 1993 (adapted from Klag and Iaboni 1987)

Source: AWMA 1992 (Adapted from Klag and Iaboni 1987).

The slag pits were water quenched after each cast during the time when these emissions were determined.

4.1.3 Steel Production

Molten iron is generally fed to a basic oxygen furnace where high-purity oxygen is blown into the molten iron (either from the top or bottom depending on the process) to oxidize the carbon and the silicon in the molten iron, and remove them from the steel. Lime is generally added to provide a slag of the desired basicity. The slag is skimmed and once it is solidified, it is conveyed to recycle facilities. Particulate, sulphur oxides and metal oxides which are the main

emissions from this process are collected by hood capture systems. No TRS emissions are reported for this process.

4.2 CONTROLS

4.2.1 Coke Oven Batteries

4.2.1.1 By-Product Coke Production

Coke Oven Doors

EQUIPMENT

Leaks between coke oven doors and door jambs are typical. They occur when there are large gaps (thousandths of an inch) between the door knife (or sealing) edge and the door jamb. Smaller gaps (millionths of an inch) are self-sealing. The tars in the COG escaping through these small gaps condense in the opening and seal it.

Past practice, when coke oven batteries were shorter, was to hand lute (seal) the opening with a clay like material (sodium silicate). The more recent practice is to maintain close tolerance between the door and the jamb. This is difficult because both the door and the jamb will warp over time (especially on the taller ovens).

Different techniques to account for these warps include: replacement of the doors and jambs, adding adjustment (springs) to a door knife edge so that it better seals against the jamb, using sealants such as sodium silicate to plug gaps and using flexible doors that are designed to bend. These flexible doors have not yet been fully tested in long term tests. It appears from initial tests that there is a significant decrease in leakage. However, depending on the operating and maintenance practices, the improvement may not be long-term and may have similar leak performance as the conventional doors that are adequately adjustable.

Sodium silicate can dramatically reduce door leaks for short periods. However the gaps between the door and jamb will continue to increase, and eventually the gap will become too large for

sealing with sodium silicate. Additionally, use of sodium silicate as a sealant makes cleaning the door and jamb more difficult.

Auxiliary gas capture devices can also be used. The two methods used are door hoods and coke side sheds. Door hoods are not generally very effective because the typical door leak is so small in relation to the distance from the leak to the hood that the escaping gas is blown away before it can reach the hood. Coke side sheds are effective at collecting almost all leaks from the side doors. If the control device on the side shed is capable of eliminating the contaminant, there should be no impact on the ambient air. Most side sheds are designed to capture and control particulate emissions.

WORK PRACTICES

The following practices are an important part of the coke oven door maintenance program.

1. Maintaining battery brickwork and the surface between the jamb and brickwork;
2. Maintaining the door sealing edge and the springs which hold it in place;
3. Proper adjustment of the door to its jamb;
4. Prior to every charge, tar and carbon buildup should be cleaned from the door seal gas channel, the door plug, both the outside and inside areas of the jamb and the leveller door;
5. Use of sodium silicate to seal leaks that are too large to self seal;
6. Ensure that the battery back-pressure is optimized;
7. Care should be taken not to damage adjacent battery surfaces when coke oven doors are removed or installed;
8. Ensure that the machine which removes or installs coke oven doors is properly spotted; and
9. Measure door latching pressure to ensure the door is properly placed and latched.

Coke Oven Lids and Off-takes

Control of these sources is generally through proper maintenance and operating procedures which involve (U.S. EPA, 1987):

- replacement of warped lids;
- cleaning carbon deposits or other obstructions from the mating surfaces or lids or their seats;
- patching or replacing cracked standpipes;
- sealing lids after a charge or whenever necessary with a slurry mixture of clay, coal, and other materials (commonly called lute); and
- sealing cracks at the base of a standpipe with the same slurry mixture.

Equipment modifications such as heavier lids and better sealing edges may also provide a better seal and automatic lid lifters can rotate the lids once they are seated to provide a better seal.

Keeping all charging lids and standpipe leaks sealed is a continuous job. Therefore, the more dedicated manpower is applied to the task the lower the emissions will be. In general, a battery may have a workforce of 4 lidmen if automatic lid lifters are used, or 8 lidmen if manual lid lifting is used.

Coke Oven Charging

Stage charging is the ordered pouring of coal by the larry car to maintain an exit space for the COG. Effective stage charging relies on close attention to detail by the operators. Levelling of the coal is also an important part of this process. Adequate aspiration to maintain a negative pressure within the oven during charging is vital. Aspiration from both ends of the oven greatly improves the COG collection efficiency and, therefore, the emissions of COG from the oven. If two collector mains are not present, jumper pipes (which connect to an adjacent oven) can be used effectively.

The larry car is often outfitted with shrouds or sleeves to prevent air infiltration and visible emissions. New hoppers have been designed which fit to the charging ports very tightly (Still-ERIN). Any air infiltration into the oven during charging can overpower the aspirators. Therefore, a seal must be maintained during charging (i.e., use a leveller boot on the chuck door).

The flow of gas within the oven must be maintained. Therefore, carbon deposits on the standpipes and goosenecks (part of the gas collection system) should be cleaned before each

charge. Carbon deposits on the roof of the oven should also be cleaned before each charge. This is generally accomplished with a scraper or air blowers on the pusher ram.

Coke Oven Pushing

Emissions from coke oven pushing may be collected by travelling hoods or coke side sheds. Emissions generally consist of carbon particulate and the gas collected by the hoods or sheds is treated to remove particulate.

AWMA 1992 reports a new control system for pushing emissions. Kress Indirect Dry Cooling (KIDC), prevents the generation of emissions so that a control system is not necessary. The pushed coke is contained so that the mass does not break up, eliminating potential emissions. The container is cooled from the outside. With this system, there are no pushing or quenching emissions.

Battery COG Venting

The only add-on control for battery venting is a flare (which is generally in place). Undesulphurized gas will release SO_2.

WORK PRACTICES

The best work practice is to prevent releases. Prevention is never perfect. However, maintaining multiple exhausters on different power systems (i.e. some on steam, some on electricity) throughout the facility and using power systems that are as independent of each other as possible can minimize battery venting incidents.

The gas released during venting incidents results from the heating of coal. Therefore, during venting incidents, it is prudent to stop coal charging and reduce the heat input to the battery. Careful attention to the wall integrity must be maintained because reduced heat input could cause damage to the walls.

Coke By-Product Recovery Plant

PROCESS CHANGES

AWMA 1992 reports that 90% of benzene (and VOC) emissions can be captured by replacing the direct-water final cooler cooling tower and naphthalene separation and processing units with either a wash-oil final cooler or a tar-bottom mixer settler with indirect cooling.

Gas blanketing is a system in which all openings in tanks are sealed and nitrogen sweep gas is used to carry the emissions back into the coke oven gas main (or control device). There has been very little experience with these systems and there are concerns expressed about tank ruptures and transmission of fires. U.S. EPA regulations require that these systems be in operation by September 1991 (AWMA 1992). A variation on this system, which has been used by at least one steel mill, is to collect the vents from the tar decanter, tar dehydrators and flushing liquor pit and route them into the coke oven gas header. Previously, these sources vented to the atmosphere through scrubbers.

Replacing sumps with pipes and tanks to reduce the amount of material exposed to air will also reduce benzene (and VOC) emissions

All of the above practices should result in lower emissions of TRS.

LEAK DETECTION AND REPAIR

Routine maintenance and repair of leaks is important to reduce fugitive emissions. The U.S. EPA currently regulates VOC emissions as follows:

- 500 ppmv above background is considered to be the level of no detectable emissions; and
- 10,000 ppmv above background is the level of a leak.

Once a leak is detected, there are time limits set for the first attempt at repair and in which to accomplish the final repair. TRS emissions will also be reduced through this practice.

4.2.1.2 Non-Recovery Battery Coke Production

There are no non-recovery battery coke units operating in Ontario and, therefore, such units are not discussed in this report.

4.2.2 Blast Furnace

Top Gas

Top gas emissions controls generally consist of collecting the top gas for use as fuel in blast furnaces, stoves, reheat furnaces, boilers etc. Any sulphur containing compounds will be released as SO_2 when the top gas is burned.

Tapping (Casting) Liquid Iron

Emissions from this source are generally collected with hoods of local collection devices and cleaned with a baghouse. Eliminating oxygen contact with liquid iron during casting can also assist in fume reduction.

Slag Processing

The quantity of pelletized slag produced depends on market conditions. The pelletized slag is more valuable and is used to manufacture sintered block. The pit slag is used for road construction and as a fill material.

Pit slag can be water quenched at the end of each cast or may be quenched after several days of collecting slag. Both Dofasco and Stelco alternate between two slag pits over 3 to 4 days. Typically, the slag is allowed to air cool for up to 24 hours before quenching with water. The water quenching lasts for about 12 hours and the slag is removed so that the pit is ready for the next cycle.

A reduction in TRS emissions has been noticed at one steel mill after increasing the size of their slag pits (done for increased capacity), though the TRS emission reduction cannot be quantified. After all of the slag is cast, it is air cooled for 36 hours. The slag is then intermittently quenched

to cool the mass and break it up into manageable pieces. The quenching cycle is 10 minutes on and 15 minutes off for 5
hours. The extended air cooling and intermittent quench both help to minimize TRS emissions. After the intermittent quenching, the slag is quenched continuously for 19 hours. The slag is then removed from the slag pit.

Concentration levels of TRS decrease with increased length of time of filling the slag pit (Rehmus et al. 1973). The amount of TRS released is a function of the temperature of the slag when it is quenched. Thus, by allowing the slag to air cool until the pit is full results in lower emissions when it is water quenched. Allowing the pit slag to air cool for an additional three days after it was filled resulted in a drop of approximately 66% in TRS emission rates (Rehmus et al. 1973).

Oxidants such as sodium hypochlorite or potassium per manganate ($KMnO_4$) have been added to the slag pit quench water. Tests have shown a 64% reduction in TRS emissions with the use of $KMnO_4$ in the quench water (Rehmus et al. 1973). The extended air cooling plus $KMnO_4$ in the quench water together resulted in approximately 84% reduction in total TRS emitted (Rehmus et al. 1973).

In laboratory experiments H_2S emissions reductions at slag pits of up to 85% have been reported using three days of cooling and potassium permanganate in the quench water (Rehmus et al. 1973).

Kaplan and Rengstorff (APCP Annual Meeting 1971) found that treatment of slag on a laboratory scale with steam, Fe_2O_3, $CaCO_3$ or CO_2 prior to granulation resulted in a 90% decrease in sulphur gases produced. However, plant trials of this technique resulted in an increase in H_2S emissions (Kaplan and Rengstorff 1971).

It has been reported that pelletized slag has lower TRS emissions as compared to pit slag (CETF 1973). However, based on the information from tests performed at Stelco and Dofasco (Table 4.5), there appears to be little difference in the mass emission rate of TRS from these two types of operations.

The emissions from slag processing are not currently contained in any manner. If all of the gases were collected it would be theoretically possible to treat the gases in a scrubber but the volume of gas to be treated is large. There are no reported installations of any gas treating systems for slag processing. The RACT/BACT/LAER summaries of control technologies do not report any controls for this source.

4.2.3 Steel Manufacturing

No TRS emissions were reported in the documents reviewed, and therefore controls are not discussed.

4.3 Steel Mills in Ontario

4.3.1 Stelco - Hilton Works Coke Ovens

Stelco currently operates five coke batteries. Batteries 3, 4 and 5 were installed between 1947 and 1953 and are approximately 4 m high. They have a total capacity of 2,900 tonnes/day and a total of 191 ovens with an average oven charge of 15 tonnes. Batteries 6 and 7 comprised of 156 ovens were installed between 1968 and 1972 and are approximately 5 m high. The total design capacity of the ovens is 4,020 tonnes/day with an average charge of 25 tonnes/oven. (Briggs C.G., *Stelco's Experience with Pushing Emissions Control Systems at Hilton Works*, presented at the Technical Conference on Control of Air Emissions from Coke Plants, 1979.)

In 1995 Stelco plans to decommission ovens 3, 4 and 5. At this time they will be trying a new process of iron production (direct coal injection) in which coal is used directly in the blast furnace to replace some of the coke. Approximately 25% of the required carbon can be supplied with pulverized coal with coke making up the rest. Because the coal will have a greater sulphur content than coke, the sulphur content of the slag could increase, as could the quantity of slag. Therefore, H_2S emissions from slag processing may increase.

The current H_2S emissions at Stelco's batteries are unknown. Since most of the coke oven batteries in the U.S. are achieving better control than the MACT limits, it was assumed that Stelco's batteries are performing at the MACT limits. Table 4.4 presents emission rates for an

average battery performing at the MACT limits. The emission rate from all of Stelco's batteries is estimated to be 0.125 g/s (Table 4.6).

Table 4.6
ESTIMATED EMISSION RATES FROM SOURCES AT STELCO

Source	Estimated TRS Emission Rate (g/s)
Coke Oven Batteries (5)	0.125
Slag Processing Pit (each) Pelletizer (each)	 14.2 10.5
By-Products Plant Tar and Sponge Oil Decanter	Negligible
Total	**24.8**

To control particulate for the coke side of the batteries there is a mist suppression system on oven batteries 3, 4 and 5. Coke oven batteries 6 and 7 have a coke side shed. There are nine wet ESPs to treat the collected gases. All batteries have a leveller boot that provides a seal around the leveller bar.

The older batteries have steam aspirators that draw the gas into a single collection main. Jumper pipes provide suction from adjacent ovens during coal loading. Coke batteries 6 and 7 have a double main collection system to provide more efficient and increased levels of suction during coal charging. The standpipes on all batteries are checked before each charge and cleaned as required.

The coke pusher ram has air blowers to clean carbon deposits from inside the top of the ovens. The oven doors are a gravity door type.

The larry cars used have magnetic lid lifters and cone-shaped sleeves that fit into the charge holes. The charging is performed sequentially and takes approximately 4 minutes. After the larry car has moved away, lid luting is applied manually to provide improved sealing.

Visible emissions are measured on a weekly basis. The methodology used is more detailed than the U.S. EPA method and the leaks are rated on a scale of 1 to 5. Stelco claims that this modification of the method allows them to better identify the source and determine the magnitude of the leak.

Door leaks are controlled with a cleaning and maintenance program. Sodium silicate may be used to seal around door jams. Leaking doors are fixed or replaced as necessary. Spray brazing and ceramic welding are used to repair doors.

The gases collected from batteries 3, 4 and 5 supply the By-Products Plant 1 while the By-Products Plant 2 is supplied by batteries 6 and 7. The coke oven gases are cooled, tar, ammonia and light hydrocarbons (benzene, toluene, xylene - BTX) are removed before final cooling and distribution. The coke oven gas is not treated for the removal of sulphur containing compounds. Based on limited emission testing estimates of these sources are shown in Table 4.6 (MOE 1986).

4.3.2 Stelco Slag Processing

At Stelco there are two blast furnaces designated "4" and "5". Blast furnace "4" produces all pit cooled slag. There are two slag pits which are used on an alternating basis. Slag is added to a pit for a period of 3 to 4 days before switching to the other pit. Typically, the east pit is used for three days and the west pit used for four days. The pits are allowed to air cool for approximately 12-18 hours for the east and wet pit, respectively. Water is used to quench for approximately 10-12 hours. The slag is allowed to stand for an additional 8 hours to allow water to drain before removal procedures are initiated.

Blast furnace "5" produces pelletized slag during the week and produces pit slag on the weekends. The slag pits are filled for two days (weekend) and the pit is allowed to air cool for approximately 3-4 hours before water quenching begins. The water quenching takes approximately 12 hours. The slag drains for approximately 8 hours before it is removed.

The quench water may be sprayed intermittently at the start of the quenching operation only when the water vapour produced interferes with blast furnace operations.

The estimated emission rates for these two operations based on measurements shown in Table 4.5 are given in Table 4.6.

4.3.3 Dofasco Coke Ovens

Dofasco operates three coke plants containing six batteries with an annual capacity of 1.7 million tons. The coke plant details are given below.

Battery No.	No. 1 Plant			No. 2 Plant		No. 3 Plant
	1	2	3	4	5	6
Date Installed (Rebuild)	1956 (1980)	1951 (1980)	1958 (1980)	1967	1971	1978
No. of ovens	25	35	45	53	53	35
Height (ft.-in.)	13-0	13-0	13-0	13-0	13-0	20-5
Door Construction	Screw latch	Screw latch	Screw latch	Screw latch	Screw latch	Screw latch
Coal coke/day (tons)	605	844	1086	1281	1281	1534
Coke produced per day (tons)	429	600	772	910	910	1090
Coke/push (tons)	11.65	11.65	11.65	11.65	11.65	20.75
Coking time (hrs)	16.3	16.3	16.3	16.3	16.3	16.0

Typically alternate ovens are charged so that the jumper pipe on the larry car vents to the adjacent oven which is approximately halfway through the coke cycle and hence not producing much off-gas. The oven is charged simultaneously with screw feeders which take approximately one minute to charge the oven. The larry cars have internal cone sleeves or an external soft seal to reduce emissions during charging. Batteries 1 and 2 have new (1992) larry cars which have a small laser that is used in spotting the car over the lids. Luting is applied manually to the lids after the charge is complete.

The coal levelling bar is inserted through the chuck door. There is no seal around the leveller bar. No emissions were observed during its operation except when it was withdrawn and a few pieces of hot coal fell out. Compressed air is used on the coke pusher ram to clean deposits from the inside top of the oven. A certain amount of deposits are desirable to seal leaks.

Emissions from the coke ovens are controlled by an inspection and maintenance program. Dofasco uses a modified version of the U.S. EPA methodology for determining leaks. Inspections are made once per day during the week. The Dofasco method is more detailed and, hence, their percentage of leaks cannot be compared to the U.S. EPA results. Included in the Dofasco method is the detailed examination of the standpipe base, standpipe cap, gooseneck and gooseneck seal with main collection pipe. The standpipes are cleaned before every charge. The charging, pusher side and chuck doors are also inspected. Records are kept of leaks and the priority of leak repair is based on the worst 25 leaking ovens over the last 30 days. The environmental performance of the coke oven batteries are evaluated on a monthly basis for trends in operation. The emissions from the coke oven batteries are assumed to be at the MACT limit (as discussed previously for Stelco). The estimated emission rate from Dofasco's batteries is estimated to be 0.15 g/s (Table 4.7).

Table 4.7
ESTIMATED EMISSION RATES FROM SOURCES AT DOFASCO

Source	Estimated TRS Emission Rate (g/s)
Coke Oven Batteries (6)	0.15
Slag Processing	
Pit (each)	14.2
Pelletizer (each)	10.5
By-Products Plant	
Stretford Tower	0.006
Washwater Cooling Tower	0.13
No. 2 Tar Decanter	0.3
Total	**25.2**

To assist with the monitoring of visible emissions from the entire site, there is a trained visible emissions observer who checks 39 sources. He records the time, length of the emission and its source of origin. The department from which the emission originates is informed, and that department then reports to the MOEE as required.

Dofasco has a rigorous leak detection and repair program in their by-product plant. The by-product plant is largely indoors and leaks must be repaired as soon as possible for safety reasons.

The COG is collected and treated in three by-products plants. As part of the process, some of the COG is treated via the Stretford process to remove sulphur. Limited information on emissions of TRS from the by-products plans is available. The MOEE conducted some source sampling (MOE 1986) at Stelco and Dofasco and the results are presented in Table 4.7. A benzene gas collection system will be installed in stages. This system will use nitrogen gas as a sweep gas through tanks and other pieces of equipment. This collected gas will be sent back to the COG booster turbine where the benzene, toluene and xylene are removed (scrubbed out) and the remaining light oil is sold.

4.3.4 Dofasco Slag Processing

Dofasco is currently operating #2 and #4 blast furnaces. Both of these furnaces are capable of producing pit and pelletized slag. The #2 blast furnace typically produces pit slag only. One pit is used for four days and another is used for three days. The slag is allowed to air cool for approximately 24 hours before quenching with water. At #4 blast furnace, slag is pelletized during the week and run into a pit on weekends.

4.4 Costs

4.4.1 Coke Oven Batteries

TRS emissions from coke oven batteries are very low compared to emissions from slagging operations (Tables 4.6 and 4.7). Therefore, reducing emissions from these sources will likely have a negligible effect on TRS emissions from the facility. The methodology for estimating control costs for coke oven batteries is presented below.

U.S. EPA 1987 presents cost factors (capital and annual components are included in the factor) for reducing emissions from coke oven charging, coke oven doors and coke oven lids and off takes. These cost factors were derived based on information supplied to the U.S. EPA by coke manufacturers (Table 4.8 and Appendix E).

Capital cost items are annualized over an average 20-year lifetime at a rate of 6.2% (after adjustment for inflation) to estimate the overall annual cost (U.S. EPA 1987). The U.S. EPA emphasizes that there is a significant element of uncertainty when using these estimates for

application to an individual battery especially when used in conjunction with the uncertainty of the mass emission estimates. Each battery should be evaluated separately on an item by item basis. However, these cost estimates are presented in this study to give an approximation of the cost which may be expected for controlling emissions from coke ovens. The U.S. EPA 1987 states that these costs probably do not understate the costs and may be somewhat higher than what would actually be incurred.

Using Table 4.8 and the figures presented for visible emissions vs. H_2S emissions (Figures 4.2 to 4.5), very approximate costs could be developed for a given H_2S reduction. For example, from Figure 4.2, assuming the visible emissions were approximately 80 s/charge, the corresponding H_2S emission rates is 0.45 g/s. To reduce H_2S emissions by 0.1 g/s, the visible emission reduction is approximately 8 s/charge. From Table 4.8, the cost to reduce charging emissions by 1 s/charge is approximately $20,000/y (CAN[1]). Therefore to reduce charging emissions by 8 s/charge the cost would be approximately $160,000/year.

This type of cost analysis could also be done for doors, lids and offtakes.

As can be seen in Figure 4.2 at low estimated visible emissions comparable to MACT levels of 12 s/charge, the H_2S emission rate approaches zero. Therefore, the estimated visible emission rates for Stelco and Dofasco are below the limit of applicability for the cost functions, described above.

4.4.2 Slag Processing

The options for the reduction of TRS emissions from slag processing are limited and difficult to cost.

Both Dofasco and Stelco fill a slag pit over a period of 3 to 4 days before water quenching the material. To use extended air cooling a third slag pit would be desirable to allow the filled pit time to air cool before water quenching. In an existing facility it would be nearly impossible to

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[1] cost/battery ($1000/year) = 840 - 20 (s/charge) (SCAN 1994)
@ 8 s/charge - cost/battery = $680,000/year
@ 7 s/charge - cost/battery = $700,000/year
Therefore to reduce visible emissions by 1 s/charge, the annualized cost is $20,000/year (SCAN 1994).

Table 4.8

CONTROL COSTS FOR VISIBLE EMISSIONS (AVERAGE VALUES AS PRESENTED IN U.S.EPA 1987)

Charging Costs ($U.S. 1984)

Facility	Capital Cost	Annualized Cost*			Operating and Maintenance Cost	s/charge	
	($1,000)	Total ($1000)	$/oven-yr	$/Mg	($1000/yr)	Baseline	Average
Empire Coke	$1,960	$236	$3,900	$1.47	$62	45.0	24.0
Bethlehem Steel	$1,889	$345	$5,400	$1.09	$178	32.0	17.0
Armco, Inc.	$3,092	$338	$5,250	$0.62	$64	25.0	17.0
U.S. Steel	[1]	$431	$5,800	$1.10	$431	19.0	9.3

Cost/battery ($1000/yr) = 560 - 13 (s/charge) ($US 1984) - annualized cost
Cost/battery ($1000/yr) = 840 - 20 (s/charge) ($CAN 1994) - annualized cost

Door Control Costs ($U.S. 1984)

Facility	Capital Cost	Annualized Cost*			Operating and Maintenance Cost	PLD	
	($1,000)	Total ($1000)	$/oven-yr	$/Mg	($1000/yr)	from	to
Empire Coke	[2]	$80	$1,355	$0.50	$80	24.0	15.0
Bethlehem Steel	$127	$185	$2,700	$0.42	$174	17.0	13.0
Armco, Inc.	$4,450	$598	$6,000	$0.71	$204	17.0	15.0
U.S. Steel	[1]	$276	$3,900	$0.66	$276	9.3	5.0

PLD - percent leaking doors
$740/oven/yr/PLD to achieve 5 PLD ($US 1984) - annualized cost
$61/oven/yr/PLD to achieve 15 PLD ($US 1984) - annualized cost
$1110/oven/yr/PLD to achieve 5 PLD ($CAN 1994) - annualized cost
$92/oven/yr/PLD to achieve 15 PLD ($CAN 1994) - annualized cost

Lid Control Costs ($U.S. 1984)

Facility	Capital Cost	Annualized Cost*			Operating and Maintenance Cost	PLL	
	($1,000)	Total ($1000)	$/oven-yr	$/Mg	($1000/yr)	Baseline	Average
Empire Coke	[2]	$32	$540	$0.20	$32	5.0	3.5
Bethlehem Steel	[2]	$57	$680	$0.13	$57	5.0	3.5
Armco, Inc.	$4	$59	$825	$0.10	$58	3.0	1.9
U.S. Steel	[1]	$118	$1,800	$0.26	$118	1.5	0.9

PLL - percent leaking lids
Cost/oven ($/yr) = 1,930 - 400 (Average PLL) ($US 1984) - annualized cost
Cost/oven ($/yr) = 2,900 - 600 (Average PLL) ($CAN 1994) - annualized cost

Offtake Control Costs ($U.S. 1984)

Facility	Capital Cost	Annualized Cost*			Operating and Maintenance Cost	PLO	
	($1,000)	Total ($1000)	$/oven-yr	$/Mg	($1000/yr)	Baseline	Average
Empire Coke	[2]	$12	$205	$0.08	$12	10.0	6.5
Bethlehem Steel	[2]	$46	$885	$0.10	$46	10.0	6.5
Armco, Inc.	$558	$86	$665	$0.10	$36	10.0	6.5
U.S. Steel	[1]	$144	$2,400	$0.33	$144	4.5	2.6

PLO - percent leaking offtakes
$420 - $610/oven/yr/PLO ($US 1984) - annualized cost
$630 - $916/oven/yr/PLO ($CAN 1994) - annualized cost

Notes
[1] reported as confidential information
[2] none reported
* Reported in U.S.EPA 1987 - Includes capital recovery of 20 years at 6.2% (capital recovery factor = 0.0886) the capital recovery factor can be found in Riggs et. al. (1986)
Chemical Engineering Index 1984 - 345.6
Chemical Engineering Index 1994 - 370.2
$CAN/$U.S (1994) - 1.4018

find more property that could be devoted to slag pits and have a means of delivering molten slag to that pit.

Extended air cooling in slag pits has produced subjective TRS emission reductions, but quantitative information information was not available for use in this study.

The use of $KMnO_4$ in the quench water has been shown in pilot studies to reduce TRS levels but there is concern with levels of manganese released from an industrial hygiene and environmental point of view. The MOEE POI criterion for manganese compounds is only 7.5 $\mu g/m^3$.

The emission data available from tests at Stelco and Dofasco show essentially the same TRS emissions from a water quenched operation and a pelletizer. Costs of switching to all pelletized or all pit slag could not be evaluated because the cost of a pelletizer was not available from Dofasco and the value of pelletized versus pit slag was not available.

The average volume of air emitted from both the water quenching and pelletizing operation is approximately 2.0×10^6 m^3/h (Klag and Iaboni 1987). Since the rate of slag flow is not constant, a peak to average ratio of 2:1 was assumed. The volume of air that would have to be treated is over 1,000 m^3/s. A scrubber of this size would have a capital cost of over $10,000,000 with a total annualized cost of $3,613,000/year (Table 4.9).

Table 4.9
Slag operations scrubber
OAQPS Costing Methodology ($Can 1994)

Total Capital Cost (TCC)	**$10,000,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$4,807,700
Direct installation cost	0.5*PEC	$2,403,900
Engineering	0.1*PEC	$480,800
Construction overhead	0.05*PEC	$240,400
Contractor Fees	0.1*PEC	$480,800
Start-up	0.02*PEC	$96,200
Performance test	0.01*PEC	$48,100
Contingencies	0.3*PEC	$1,442,300
Total Capital Cost	**2.08*PEC**	**$10,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$500,000
Overhead (60% of labour and maintenance costs)		$313,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$748,400
Administrative	2% of TCC	$200,000
Property taxes	1% of TCC	$100,000
Insurance	1% of TCC	$100,000
Operating and Maintenance Cost (O&M)		**$1,985,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$1,628,000
Total Annualized Cost		**$3,613,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 12684480

5.0 SILICON CARBIDE ABRASIVE MANUFACTURE

5.1 SILICON CARBIDE MANUFACTURE

Silicon carbide (SiC) is produced from silica sand and petroleum coke in a gaseous phase fusion reaction:

$$SiO_2 + 3C \rightarrow SiC + 2CO$$

The reaction takes place at approximately 2,000°C in an electric arc furnace. The silica sand and the petroleum coke are piled in the furnace. Powdered graphite is placed in forms on top of the raw materials. The graphite is covered with more sand and coke. An electric current is passed through the graphite which increases the temperature of the raw materials.

Petroleum coke typically contains 1.5 to 10% (by weight) sulphur (Perry's Handbook 1984). Under the reducing atmosphere within the furnace, the sulphur reacts with the hydrogen in the coke and is released as H_2S.

5.2 TREIBACHER SCHLEIFMITTEL

5.2.1 Plant Operation

SENES Consultants Limited visited Treibacher Schleifmittel in Niagara Falls on 7 October 1994. Treibacher Schleifmittel is the only producer of silicon carbide in Ontario. At the time of construction, Treibacher Schleifmittel was the largest SiC furnace in the world producing on the order of thousands of tons of SiC per batch.

Treibacher has two circular furnaces which are enclosed in geodesic domes (height of 22 m). The mixed raw materials are piled between the electrode ends. A conveyor system brings the raw materials into the dome and a crane which pivots around the centre of the dome distributes the material where required. The graphite electrode is built in place and then covered with more raw material. Direct Current (DC) is applied through the electrode starting at a low rate and ramping up with time. Once current is applied, no further access into the dome is allowed due to emission of carbon monoxide (CO) and H_2S.

The reaction is observed through the use of infrared remotely-controlled cameras. Additional raw material is added, as required, as the reaction proceeds. It takes approximately 21 days to complete this batch reaction. For the first four or five days, there is little evolution of gases. As the temperature of the furnace approaches 2,000°C the gas phase reaction proceeds, producing SiC in crystalline form.

Air is withdrawn from the top of the dome to maintain a slight negative pressure within the dome. This reduces fugitive emissions from the domes and increases the yield of SiC. Once the pressure within the underpipe reaches a critical value, gases are withdrawn from under the furnace and incinerated. The volume of gas withdrawn from the bottom of the furnace cannot be increased. In the past, this practice resulted in a meltdown of refractory material which caused plugging of the underpipe and lost production. The emissions from the top of the dome and the incinerator are collected and are released (approximately 8,900 m^3/min) from a 46 m stack.

After the end of the 21 day cycle, the furnace is allowed to cool. Water is sprayed on the furnace to further cool it. The unreacted raw materials are separated from the product and stored in a silo for reuse. While the dome is being unloaded, the air withdrawn from the top is passed through a baghouse to collect particulate. The product is allowed to cool in a warehouse and sized before shipping to customers.

The two furnaces are operated alternatively. While the one furnace is producing product the other is being unloaded and then is set up for the next run.

The production of SiC uses substantial quantities of electricity with the costs of the electricity making up a large portion of the costs of manufacturing the SiC. The plant typically operates when the cost of electricity is lower (spring and fall). At the time of the construction of the plant, there was an economic incentive to be close to the generating source of electric power. However, since that time, the costs of electricity have been equalized across the province.

This site also produces aluminum oxide (Al_2O_3) in a separate operation. There are no emissions of H_2S from this process.

5.2.2 H_2S Emissions

Hydrogen sulphide is released from the stack and from fugitive leaks around the domes. Due to the very corrosive atmosphere within the domes, the aluminum panels which enclose the domes have been degraded over the years. In 1987, Treibacher initiated a program to refurbish the domes. The lower aluminum panels and badly corroded panels have been replaced. Tension rings and ductwork have also been replaced.

Treibacher has also found that spraying polyurethane foam on the insides of the domes has helped to reduce corrosion within the domes. This is applied about once per year. Since the foam application began, Treibacher has noticed that they can better maintain negative pressure within the domes.

Treibacher intends to replace a few more of the badly corroded panels, and continue to spray the interior of the domes with polyurethane foam. In addition, they will replace doors and other parts as necessary.

5.2.2.1 Emission Rate Estimates

Stack testing was conducted from 10 August 1992 to 14 August 1992 at Treibacher. The tests were carried out approximately two-thirds of the way through the 21-day cycle. The furnace in the East Dome (see Plant Layout - Figure 5.1) was running at full capacity during the test. The H_2S concentration in the stack was measured at 50 ppm, the sulphur dioxide concentration 3 to 4 ppm and the CO concentration at 5,000 ppm. The emission rate of H_2S was determined to be approximately 8 g/s.

To estimate the fugitive emissions from the dome, air dispersion modelling of the facility was conducted. Figure 5.2 shows the measured TRS concentrations (for 24 May 1993) at the monitor located at 27055 Stanley Avenue, Niagara Falls (Figure 5.3).

The Industrial Source Complex (ISC) model was used to estimate the emission rate from the stack and the dome which would be necessary to reach the concentrations measured. The dome was modelled as an elevated area source with a height of 11 m.

The contribution from the stack at the monitoring station which is located about 650 m away was found to be minimal (1.2 ppb maximum). The highest predicted concentration (12 ppb) downwind from the stack on 24 May 1993 occurred within 250 m of the stack.

Assuming an emission rate from the dome of 8 g/s, gives the one hour average concentrations presented in Table 5.1. The calculated concentrations are within the right order of magnitude of the measured values. For example, the one hour average concentration measured at 7:00 a.m. (see Figure 5.2) was 39 ppb. The calculated one hour average for 7:00 a.m. is 40.1 ppb. Therefore, an emission estimate of 8 g/s for the dome modelled as an area source is a reasonable estimate.

To ensure that the quantity of H_2S emitted from the stack and dome as determined above is not greater than is possible, the theoretical amount of H_2S which could be released was also determined according to the following assumptions:

- SiC production ≡ 10,000 tons/year (½ year production);
- operate ~ 26 weeks/year;
- 1.2 ton coke/ton SiC produced;
- sulphur content of coke is 3.5%; and
- 93% of sulphur is released as H_2S.

Approximately 19 tons H_2S could be released per batch of SiC produced. Assuming that the H_2S is released equally throughout the production period results in an emission rate of 11 g/s. The emissions, however, are not equal over the period, therefore, a total emission rate of 16 g/s from the stack and the domes is possible.

5.2.3 H_2S Emissions Controls in the Silicon Carbide Industry

There is very little information available on other silicon carbide manufacturing processes. Exolon ESK is located in Hennepin Illinois. This facility is entered into the BACT/LAER database for control of SO_2 emissions.

Exolon ESK has four small silicon carbide furnaces. These furnaces are enclosed in polyethylene sheets (approximately 0.3 mm thick). As the furnace increases in temperature, the polyethylene

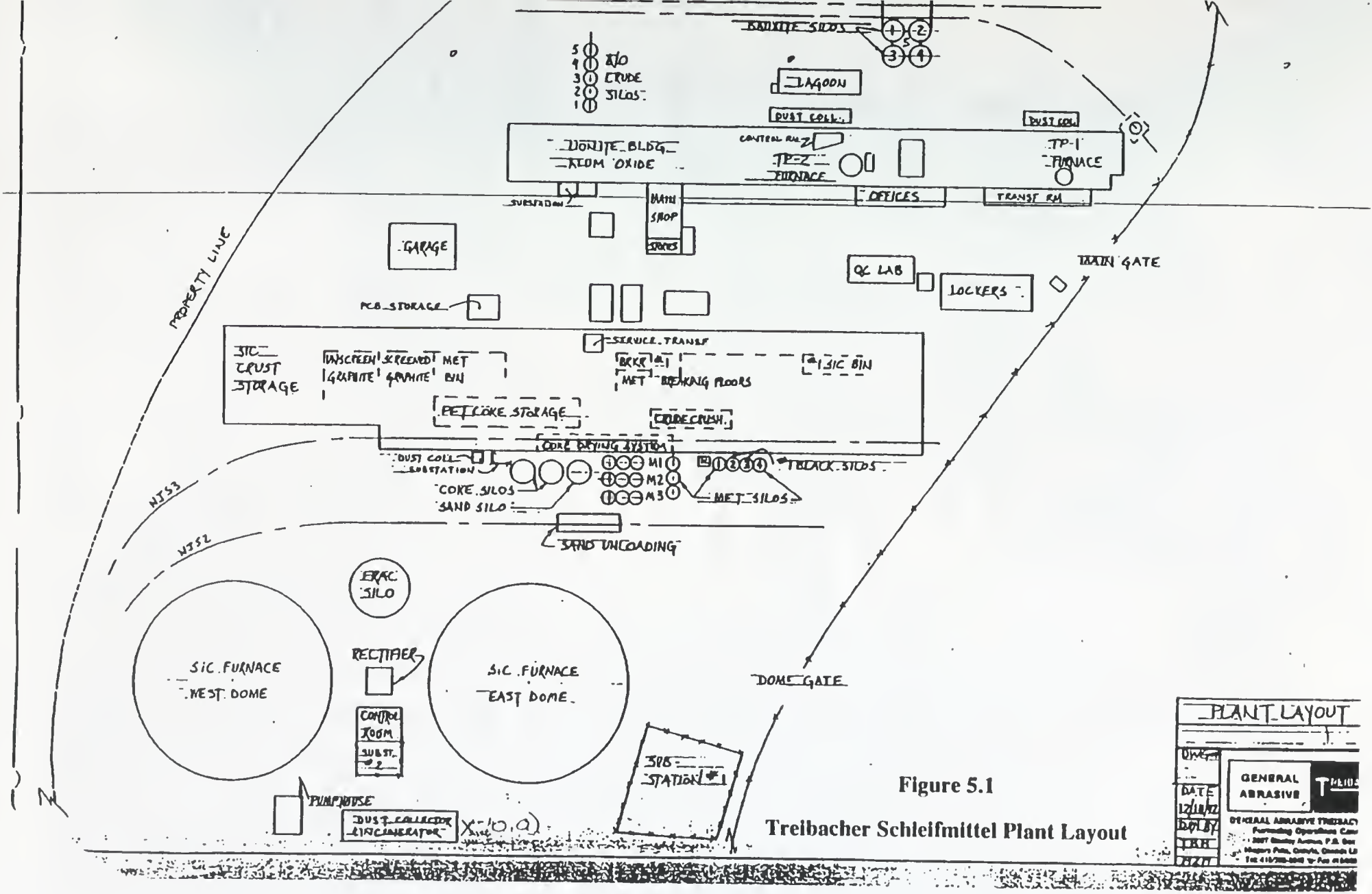

Figure 5.1

Treibacher Schleifmittel Plant Layout

Figure 5.2

Measured TRS Concentrations at Station 27055

WEST CENTRAL REGION (HAMILTON)
Mon MAY 24, 1993

Station : 27055 NIAGARA GEN. A. Parameter : TOTAL REDUCED SULPHUR Units : PPB

93/05/24/10:05 TO 93/05/24/01:00
0 0 0 0 1 2 4 5 3 4 4 3 3 2 4 3
BLOCK MIN, MAX, AVG : 2 5 4

93/05/24/05:05 TO 93/05/24/06:00
5 2 4 2 5 4 2 3 1 4 4 26A
BLOCK MIN, MAX, AVG : 1 26 5

93/05/24/06:05 TO 93/05/24/07:00
38A 40A 42A 35A 35A 35A 22A 39A 50A 54A 41A 39A
BLOCK MIN, MAX, AVG : 22 54 39

93/05/24/07:05 TO 93/05/24/08:00
48A 50A 39A 45A 40A 36A 40A 44A 54A 51A 56A 55A
BLOCK MIN, MAX, AVG : 36 59 47

Enter E to exit, anything else to continue_

93/05/24/09:05 TO 93/05/24/09:00
63A 36A 34A 27A 27A 28A 44A 30A 57A 54A 64A 62A
BLOCK MIN, MAX, AVG : 27 64 43

93/05/24/09:05 TO 93/05/24/10:00
65A 46A 44A 40A 25A 22A 20A 19 46A 34A 47A 27A
BLOCK MIN, MAX, AVG : 19 65 36

93/05/24/10:05 TO 93/05/24/11:00
22A 30A 46A 37A 42A 44A 46A 49A 33A 14 15 15
BLOCK MIN, MAX, AVG : 14 49 33

93/05/24/11:05 TO 93/05/24/12:00
26A 15 35A 22A 29A 48A 44A 55A 42A 22A 36A 13
BLOCK MIN, MAX, AVG : 13 55 32

93/05/24/12:05 TO 93/05/24/13:00
12 0 7 0 12 5 4 5 1 8 4 11
BLOCK MIN, MAX, AVG : 0 12 6

93/05/24/13:05 TO 93/05/24/14:00
6 3 2 5 -1 -2 3 1 3 4 4 6
BLOCK MIN, MAX, AVG : -2 6 3

93/05/24/14:05 TO 93/05/24/15:00
0 19 5 7 15 9 5 4 8 1 4 7
BLOCK MIN, MAX, AVG : 0 19 7

93/05/24/15:05 TO 93/05/24/16:00
1 8 5 13 11 11 3 6 18 20A 28A 2
BLOCK MIN, MAX, AVG : 1 28 11

Enter E to exit, anything else to continue_

93/05/24/16:05 TO 93/05/24/17:00
21A 25A 16 16 17 32A 8 14 30A 17 11 27A
BLOCK MIN, MAX, AVG : 8 32 20

93/05/24/17:05 TO 93/05/24/18:00
46A 40A 45A 56A 37A 43A 36A 14 27A 44A 24A 18
BLOCK MIN, MAX, AVG : 14 56 36

93/05/24/18:05 TO 93/05/24/19:00
14 6 17 25A 29A 42A 37A 40A 31A 34A 40A 38A
BLOCK MIN, MAX, AVG : 6 42 29

93/05/24/19:05 TO 93/05/24/20:00
17 7 14 6 6 6 4 6 6 2 26A 36A
BLOCK MIN, MAX, AVG : 2 36 11

93/05/24/20:05 TO 93/05/24/21:00
53A 40A 32A 49A 37A 42A 12 12 21A 31A 27A 27A
BLOCK MIN, MAX, AVG : 12 53 32

93/05/24/21:05 TO 93/05/24/22:00
30A 5 5 7 6 6 4 6 13 37A 11 14
BLOCK MIN, MAX, AVG : 4 37 12

93/05/24/22:05 TO 93/05/24/23:00
17 36A 27A 27A 44A 26A 34A 49A 9 12 12 14
BLOCK MIN, MAX, AVG : 5 49 26

93/05/24/23:05 TO 93/05/24/24:00
12 15 29A 22A 24A 26A 28A 8 9 7 5 11
BLOCK MIN, MAX, AVG : 5 29 16

21 half hours ov
H_2S std

max : 51ppb

start : 0700 E

source : General

11 thincident of

NOTE STIX
FAX TRANSMITTAL MEMO

# of pages ▸ 2

To Chris Marson
Co. Senes Consultant
Dept.
Fax # 905-764-9386
From Eric Loi
Co. MOEE
Phone # (416) 323-5146
Re: Gen. Abrasive Data.

Wind on revel

Figure 5.3

Station 27055 - Niagara Falls

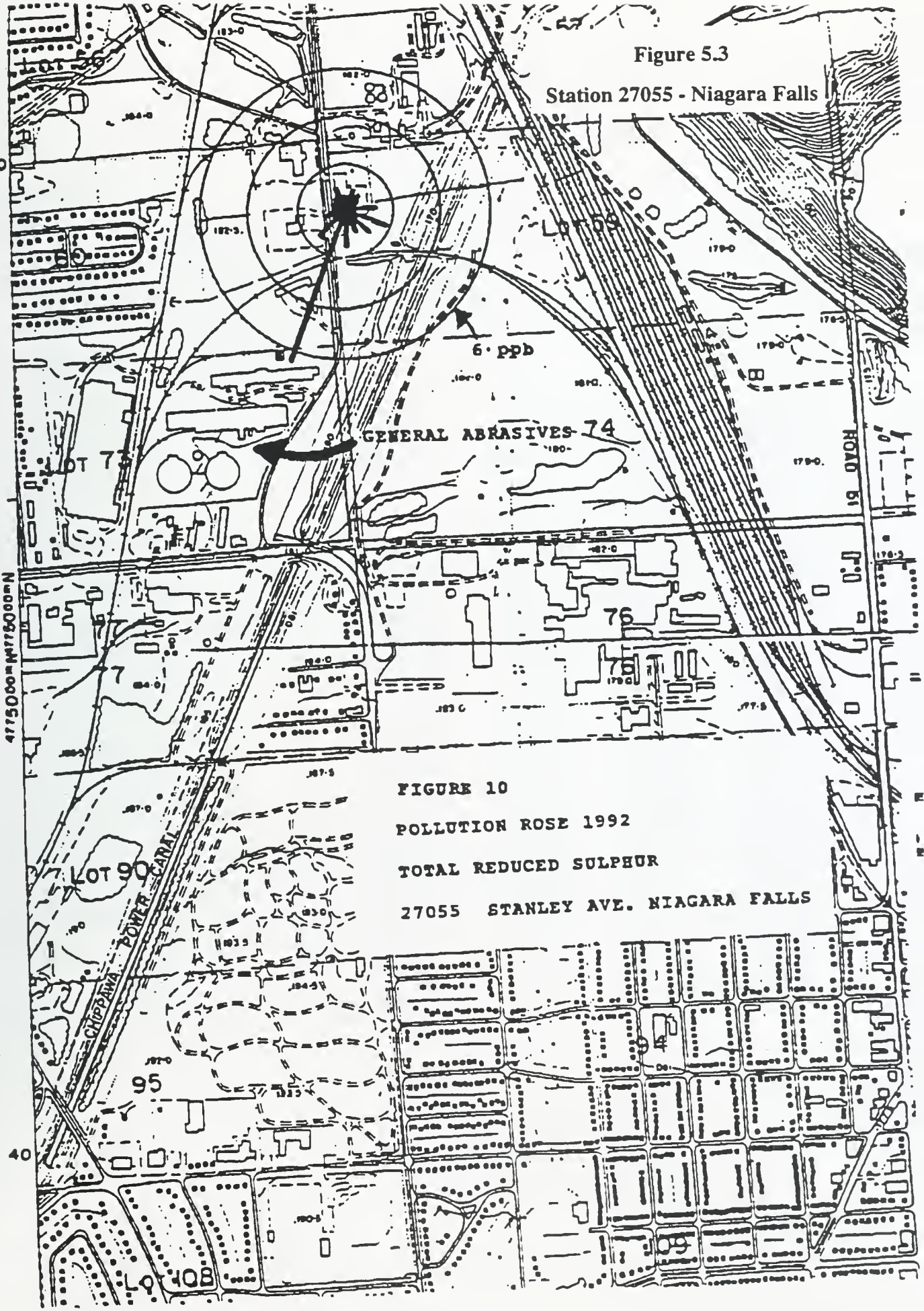

Table 5.1

ISCST Model Results for Treibacher Schleifmittel

```
* ISCST2 (93109): Treibacher Schleifmittel - stack emissions
* MODELING OPTIONS USED:
*  CONC   RURAL  FLAT        DFAULT
*         MAXI-FILE FOR  1-HR VALUES >= A THRESHOLD OF      .00
*         FOR SOURCE GROUP: ALL
*         FORMAT: (1X,I3,1X,A8,1X,I8,2(1X,F13.5),2(1X,F7.2),1X,F13.5)
*AVE   GRP     DATE         X            Y          ELEV    FLAG      CONC (ppb)
*
   1 ALL      93052401   245.00000    600.00000     .00     .00      .00000
   1 ALL      93052402   245.00000    600.00000     .00     .00      .00000
   1 ALL      93052403   245.00000    600.00000     .00     .00      .00017
   1 ALL      93052404   245.00000    600.00000     .00     .00      .00621
   1 ALL      93052405   245.00000    600.00000     .00     .00      .00019
   1 ALL      93052406   245.00000    600.00000     .00     .00      .05955
   1 ALL      93052407   245.00000    600.00000     .00     .00    40.12186
   1 ALL      93052408   245.00000    600.00000     .00     .00    28.58437
   1 ALL      93052409   245.00000    600.00000     .00     .00    10.86445
   1 ALL      93052410   245.00000    600.00000     .00     .00    45.96172
   1 ALL      93052411   245.00000    600.00000     .00     .00    47.00388
   1 ALL      93052412   245.00000    600.00000     .00     .00    45.95678
   1 ALL      93052413   245.00000    600.00000     .00     .00     6.73663
   1 ALL      93052414   245.00000    600.00000     .00     .00    16.50508
   1 ALL      93052415   245.00000    600.00000     .00     .00    27.90552
   1 ALL      93052416   245.00000    600.00000     .00     .00    36.18523
   1 ALL      93052417   245.00000    600.00000     .00     .00    41.86845
   1 ALL      93052418   245.00000    600.00000     .00     .00    35.86657
   1 ALL      93052419   245.00000    600.00000     .00     .00    52.60880
   1 ALL      93052420   245.00000    600.00000     .00     .00    57.03888
   1 ALL      93052421   245.00000    600.00000     .00     .00     5.08204
   1 ALL      93052422   245.00000    600.00000     .00     .00      .21612
   1 ALL      93052423   245.00000    600.00000     .00     .00    59.85913
   1 ALL      93052424   245.00000    600.00000     .00     .00    68.38729
```

sheets inflate (similar to a bubble). The gases are drawn from the enclosure as they are produced (70 m^3/min) and incinerated. Exolon ESK had intended to collect the incinerated gas and purify it in a patented process for use as fuel. In a discussion with Chris Romain of the Illinois EPA, Division of Air Pollution Control (14 October 1994), SENES found that this process will not take place as planned. The facility is under an order to control SO_2 emissions and is investigating a Dow sulphur recovery system, a Claus system and a modified Stretford system (no methanol recovery) for control of SO_2 alone. Their uncontrolled SO_2 emissions are approximately 4,200 ton/y SO_2 (Romain 1994).

The annualized cost for the SO_2 controls discussed above is approximately $2,000,000/year (U.S.) and the cost effectiveness is approximately $600/ton SO_2 (U.S.) - no further detail was provided (Romain 1994).

Another facility located in the Netherlands is called Elektroshmelzwerk Delfzil B.V. This facility reports a reduction of 90% in SO_2 emissions (Laurijsen 1990). This facility does not incinerate its emissions. It converts the H_2S to elemental sulphur in a LO-CAT reactor. This is a scrubber which utilizes chelated iron as a catalyst for conversion. The H_2S concentration in the raw gas is approximately 0.5 to 3%.

5.2.4 H_2S Emissions Controls and Costs at Treibacher

The volume of gas withdrawn from the domes is substantial (approximately 8,900 m^3/min) and the concentration of H_2S in the stack gas is approximately 50 ppm. The controls applied to the facilities discussed in Section 5.2.3 cannot be economically applied to Treibacher. The volume of gas at Treibacher is approximately 24 times higher and the H_2S concentration is much lower (50 ppm vs. 5,000 ppm).

Alternative potential controls for this facility include:

- Dilution (stack 2.5 times building height);
- Operational Control - real time control based on wind direction;
- Process Control - turn down current - longer cook;
- Source Control - use petroleum coke with a lower sulphur content;
- Leak Detection and Repair;

- Scrubbing; and
- Incineration.

The stack is currently approximately twice the height of the domes. At this height,emissions may be captured by building wake effects and brought to the surface near the plant. Increasing the height of the stack to two and a half times the building height (good engineering practice - GEP) could provide greater dispersion and reduce the off property concentrations. Based on the OAQPS methodology (described in Handbook - Control Technologies for Hazardous Air Pollutants), the approximate capital cost to increase the height of the stack from 150 ft. to 225 ft. is $320,000 (assuming carbon steel construction). To construct a free-standing 225 ft. stack, the approximate capital cost is approximately $775,000.

The ISC model was run to simulate the impact of increasing the stack height to 225 ft. The highest ground level concentration from stack emissions with the 150 ft. stack was found to be 12 ppb approximately 250 m from the stack. Raising the stack to 225 ft. gives a maximum ground level concentration of 2.6 ppb approximately 2,280 m from the stack. These results indicate that there may be a building wake effect with the current stack configuration.

Operational control is used for major sources of contaminants such as SO_2 in Ontario and they are coupled to process control which limits emissions under poor dispersion conditions. At Treibacher, lowering the current level, reduces not only the emissions from the process, but it also reduces the quality of the product. The product is sold by weight of SiC. There are essentially two product lines, + 95% or 88 to 92%. Material lower in SiC content than 88% is sold at a substantially lower price and is uneconomical (Ciccarelli 1994). Runs in which Treibacher have had to shorten a run or reduce the power level during the run have resulted in at least a 15% loss of product. In several cases, no material was produced with a + 95% SiC content.

Treibacher is currently paying approximately $45/ton (U.S.) for its petroleum coke feed. The coke has a sulphur content of about 3.5%. Treibacher uses 1.2 tons coke/ton SiC produced and therefore release approximately 400 tonnes H_2S/y in a typical year (when they run for 26 weeks), they produce 10,000 tons of SiC. Their coke usage in a year is approximately 12,000 tons costing about $540,000 ($760,000 CAN).

Coke with a sulphur content of approximately 1% is currently selling for about $100/ton (U.S.). If Treibacher were to use 1% coke, their costs would then be about $1,200,000/year ($1,682,000 CAN) and their sulphur emissions would reduce by approximately 70% or 280 tonnes H_2S/year. The cost effectiveness of this option is estimated to be $3,300/tonnes H_2S removed (CAN).

Because overburden is continuously added to the furnace pile during the SiC manufacturing process, covers which would contain the released H_2S in a highly concentrated stream are not a viable option. Consequently, the control techniques proposed for Exolon ESK in the U.S. and Elektroshmelzwerk in Holland could not be considered. It may be possible to allow the concentrations to build up within the domes at Treibacher, however this could lead to greater fugitive loses and other operational problems. This would have to be evaluated in more detail.

Leak detection and repair is a control option that Treibacher is currently undertaking. Over a three-year period, Treibacher has invested $600,000 to $700,000 in dome repair or approximately $200,000/year. In addition, they have turned off and sealed their axial fans. Over the period from 1990 to 1992 the average TRS concentration measured at 27055 Stanley Avenue dropped from 3.1 ppb in 1990 to 2.4 ppb in 1991 and to 1.5 ppb in 1992 (MOEE 1993). This reduction is probably partly due to the dome repair efforts at Treibacher. If it is assumed that the TRS concentrations measured at 27055 Stanley Avenue are due to emissions primarily from the Treibacher domes, than it can also be assumed that over a two-year period the emissions from the domes were reduced by approximately 50%. Based on the air dispersion modelling conducted (discussed in Section 5.2.2), the emission rate from the domes in 1993 was determined to be 8 g/s. If there was a 50% reduction in emissions from 1990 to 1992 the emission rate from the domes in 1990 was approximately 16 g/s. Production at Treibacher also dropped over the 1990-1992 period. Quantifying the amount of reduction due to reduced production vs. improved dome repair would require a more detailed modelling study.

Better leak repair will not reduce the overall mass emissions from Treibacher. What does not escape from the domes will be released from the stack. However, there is much greater dispersion from the stack.

Because of the large air flow rates at Treibacher, the cost of operating a scrubber or incinerator for the low-levels of TRS are very high. The capital cost of the scrubber (65% reduction) is estimated to be $10,000,000 ($CAN 1994) with operating and maintenance costs in the order of

$500,000/year. The annualized cost for a scrubber for this source is estimated to be $3,061,000. See Table 5.2 for details.

The capital cost of an incinerator (with no heat exchanger) (94% reduction) was estimated to be approximately $307,000 according to the OAQPS methodology (U.S.EPA 1992). Table 5.3 details the calculation for operating and maintenance cost ($3,077,000/year) and the annualized cost ($3,127,000).

The costs for the different control alternatives and the cost effectiveness is given in Table 5.4. Table 5.4 indicates that using lower sulphur coke is the most cost-effective solution.

Table 5.2
Abrasives Manufacture scrubber
OAQPS Costing Methodology ($Can 1994)

Total Capital Cost (TCC)	**$10,000,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$4,807,700
Direct installation cost	0.5*PEC	$2,403,900
Engineering	0.1*PEC	$480,800
Construction overhead	0.05*PEC	$240,400
Contractor Fees	0.1*PEC	$480,800
Start-up	0.02*PEC	$96,200
Performance test	0.01*PEC	$48,100
Contingencies	0.3*PEC	$1,442,300
Total Capital Cost	**2.08*PEC**	**$10,000,000**

Total Annualized Cost operating days/year 183

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$11,000
Supervisory Labour	15% of operating labour	$1,700
Maintenance Cost	5% of TCC	$500,000
Overhead (60% of labour and maintenance costs)		$307,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$212,200
Administrative	2% of TCC	$200,000
Property taxes	1% of TCC	$100,000
Insurance	1% of TCC	$100,000
Operating and Maintenance Cost (O&M)		**$1,433,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $1,628,000
Total Annualized Cost		**$3,061,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 3596049

Table 5.3
Abrasives Manufacture Incinerator
OAQPS Costing Methodology ($Can 1994)

Total Capital Cost (TCC)	**$307,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$147,600
Direct installation cost	0.5*PEC	$73,800
Engineering	0.1*PEC	$14,800
Construction overhead	0.05*PEC	$7,400
Contractor Fees	0.1*PEC	$14,800
Start-up	0.02*PEC	$3,000
Performance test	0.01*PEC	$1,500
Contingencies	0.3*PEC	$44,300
Total Capital Cost	**2.08*PEC**	**$307,000**

Total Annualized Cost operating days/year 183

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$11,000
Supervisory Labour	15% of operating labour	$1,700
Maintenance Cost	5% of TCC	$15,400
Overhead (60% of labour and maintenance costs)		$16,900
Utilities (fuel)	$3.30/1000ft^3	$2,948,600
Utilities (electricity)	$0.059/kwh	$70,700
Administrative	2% of TCC	$6,100
Property taxes	1% of TCC	$3,100
Insurance	1% of TCC	$3,100
Operating and Maintenance Cost (O&M)		**$3,077,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $50,000
Total Annualized Cost		**$3,127,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) 893520
electricity (kWh/y) (estimated based on OAQPS) 1198683

Table 5.4

Cost Summary for Treibacher Schleifmittel ($CAN 1994)

Control	Capital Cost ($CAN 1994)	Operating and Maintenance Cost ($CAN 1994/y)	Annualized Cost ($CAN 1994/y)	Uncontrolled Emission Rate (t/y)	Controlled Emission Rate (t/y)	TRS Emissions Reduction (t/y)	Cost Effectiveness ($/t TRS removed)
Construct a higher stack	$320,000-$775,000			400	0	0	
Use of reduced sulphur coke[1]	-	$922,000	$922,000	400	120	280	$3,300
Dome leak detection and repair			$200,000	400	?	0	
Scrubber	$10,000,000	$1,433,000	$3,061,000	400	140	260	$12,000
Incinerator	$307,000	$3,077,000	$3,127,000	400	24	376	$8,000

[1] increased cost of switching to coke with 1% sulphur

6.0 CONCLUSIONS AND RECOMMENDATIONS

The completeness and accuracy of the emission inventories for all of the facilities studied is unclear. Details are discussed in the industry specific sections below.

The *O.Reg 346* modelling results that were available for some of the facilities will not represent reality for these complex facilities. Building wake is an important factor that affects predicted ambient concentration close to the buildings. The *O.Reg 346* model does not take this into account. Also only "C" and "D" atmospheric stability classes and a limited number of wind speeds are considered by the model.

Furthermore, the quality of the *O.Reg 346* modelling undertaken is not known as the results are generally presented without a clear indication of where buildings are located and where property lines are. It was not possible to determine whether or not the modelling methodology was consistent from year to year.

Using point-of-impingement regulations means that the reduction(s) required by each facility depends on the size of the facility's property and the location of the facility relative to the property line. The actual costs that would be incurred for each facility depend on the proximity of the facility to the property line.

The costs for backup control systems were not considered as part of this project. For the pulp mills, an example of a backup, is a system to handle the NCGs in case of a malfunction of the primary control (lime kiln).

6.1 PULP MILLS

The emission data available from the three pulp mills studied were quite variable from year to year. Little discussion of the measured emission rates was included in the available reports. It is not known whether a reduction in TRS from one year to the next was due to a change in a process, a solution to a previous problem or some other factor like a change in production. Thus it is not clear which measurements more accurately represent routine operations at the mills.

The same stacks were not tested at each mill. Thus, the completeness of the mills emission inventory is unknown.

The stack testing methodology was investigated by the MOEE for Malette only. The MOEE had some concerns about the methodology used. No information was available on the acceptability of the methods used at the other mills.

Costing information is available for pulp mill-specific control technologies. This information has been compiled and the generic costs for controls have been applied to the individual pulp mills discussed in this study. Specific control options have been presented for the individual pulp mills. The feasibility of the different control options will have to be assessed by each pulp mill.

6.2 Steel Mills

Based on estimates of mass emission rates of TRS from the coke batteries and the slag pelletizing operations (Tables 4.6 and 4.7) it would appear that the slag processing operations contribute the majority of the TRS emissions from a steel plant.

However, the data available on emissions from slag processing are poor and it is recommended that further testing of both pit and pelletized slag emissions be undertaken. The options for the reduction of TRS emissions from slag processing are limited and difficult to cost because the system is not enclosed and there were no systems identified in our literature search and through our contacts which could provide cost estimates. Extended air cooling in slag pits has produced subjective TRS emission reductions, but quantitative information was not available for use in this study.

The main concern from coke ovens has been visible emissions. There is very limited data available on TRS emissions from coke ovens. The U.S. EPA methodology for determining leakage from coke ovens deals solely with visible emissions. Both Stelco and Dofasco follow modified versions of the U.S. EPA methodology and results are not comparable. The estimates of TRS emissions from coke ovens have a great deal of uncertainty associated with them.

With the currently available data, it would appear that coke ovens are a minor source of TRS emissions compared to the slag operations. Further studies should be undertaken to determine actual emissions of TRS from representative coke ovens.

There is also potential for TRS emissions from the by-products plant (coke gas processing facilities) but there is very little data available. Actual emission rates should be measured from this area. Both facilities studied have a leak detection and repair program but no quantification of TRS emissions have been made.

Since emission data is limited, only generic costing of different control options was possible.

6.3 TREIBACHER SCHLEIFMITTEL

The emission estimates for this facility are based on stack sampling tests performed at a single point in time in a variable process. The TRS emission rate varies over time as the batch process proceeds. More measurements over the entire batch cycle would be required to fully characterize the emissions.

The preliminary air dispersion modelling carried out indicates that Treibacher's leak detection and repair program is very important in preventing elevated ambient levels of TRS.

Reducing the sulphur levels in the petroleum coke (control at source) would result in lower levels of emission at lowest cost from this facility until other types of control can be investigated for technical and economic feasibility. The estimated TRS reduction using a lower sulphur coke (1% S) would be about 70%.

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ABBREVIATIONS

$CAN 1990	-	1990 Canadian dollars
$US 1990	-	1990 United States dollars
$\mu g/m^3$	-	microgram per cubic meter
ADP	-	air dry pulp
ADt	-	air dry tonne (@ 10% moisture) (pulp)
ADT	-	air dry ton (@ 10% moisture) (pulp)
Al_2O_3	-	aluminum trioxide
AWMA	-	Air and Waste Management Association
BACT	-	best available control technology
BLO	-	black liquor oxidation
BLS	-	black liquor solid
BOD	-	biological oxygen demand
BSO	-	benzene soluble organics
Btu	-	British Thermal Units
C of A	-	Certificate of Approval
CaC_2	-	calcium carbide
$CaCO_3$	-	calcium carbonate
$CaCO_3$	-	calcium carbonate
CaO	-	calcium oxide
CaS	-	calcium sulphide
cfm	-	cubic feet per minute
CO	-	carbon monoxide
CO_2	-	carbon dioxide
COG	-	coke oven gas
d	-	day
DC	-	direct current
ESP	-	electrostatic precipitator
Fe_2O_3	-	ferric oxide
FRP	-	fibre reinforced plastic
ft.	-	feet
$ft.^2$	-	square feet
$ft.^3$	-	cubic feet

sft^3	-	cubic feet at standard conditions
g/s	-	grams per second
GJ	-	gigajoules = 10^9 joules
GLC	-	ground level concentration
gpm	-	gallons per minute
h	-	hour
H_2S	-	hydrogen sulphide
HAP	-	hazardous air pollutant
HCLV	-	high concentration low volume
ISC	-	Industrial Source Complex (model)
kg	-	kilograms
kWh	-	kilowatt hours
LAER	-	lowest achievable emission rate
lb.	-	pounds
LCHV	-	low concentration high volume
m	-	metres
M	-	mega - 10^6
m^2	-	square metres
m^3	-	cubic metres
m^3/s	-	cubic meters per second
Nm^3/min	-	normal cubic meters per minute
MACT	-	maximum achievable control technology
mg	-	milligram = 10^{-3} grams
Mg	-	megagram (tonne) = 10^6 grams
min	-	minute
mmBtu	-	million Btu
MMlb	-	million pounds
MOEE	-	Ministry of Environment and Energy (for Ontario)
Na_2CO_3	-	sodium carbonate
Na_2S	-	sodium sulphide
NaOH	-	sodium hydroxide
NCASI	-	National Council for Air and Stream Improvement
NCG	-	non-condensible gas
NESHAP	-	National Emissions Standards for Hazardous Air Pollutants

NO_x	-	nitrogen oxides
NSPS	-	New Source Performance Standards
O.Reg.	-	Ontario Regulation
O_2	-	oxygen
OAQPS	-	Office of Air Quality Planning and Standards (Control Cost Manual - Fourth Edition)
PLD	-	percent leaking doors
PLL	-	percent leaking lids
PLO	-	percent leaking offtakes
POI	-	point of impingement
ppb	-	parts per billion
ppmv	-	parts per million by volume
RACT	-	reasonably achievable control technology
s/charge	-	seconds per charge
scfm	-	standard cubic feet per minute
SiO_2	-	silicon dioxide
SO_2	-	sulphur dioxide
t	-	tonne
T	-	ton
TRS	-	total reduced sulphur
TSP	-	total suspended particulate
U.S. EPA	-	United States Environmental Protection Agency
VOC	-	volatile organic compound
wt.%	-	weight percent
y	-	year
°C	-	degrees Celsius
°F	-	degrees Fahrenheit

GLOSSARY

AP42	-	compilation of air pollution emission factors presented in U.S. EPA 1985 and U.S. EPA 1994
black liquor	-	spent cooking liquor from a kraft cook, containing dissolved organic wood materials and residual alkali compounds
blow	-	pulp is discharged under pressure from digester
brownstock	-	pulp before bleaching
calcining	-	lime mud ($CaCO_3$) is dried and heated to form quicklime (CaO) and carbon dioxide
charge	-	loading of raw materials (coal) into reaction vessel
chuck door	-	small access door on pusher side of coke ovens through which leveller bar is inserted
coke side	-	side of coke oven where finished coke is quenched (see pusher side)
coking	-	process of heating coal under anaerobic conditions to form coke (essentially pure C with low levels of impurities)
contaminated condensate	-	process condensate from multiple effect evaporators that is reused without stripping in recausticizing and brownstock washing
cooking	-	treating fibrous raw materials under heat and pressure to produce pulp for paper making

direct contact evaporator	-	strong black liquor from the multiple effect evaporator is concentrated from 55% solids to approximately 65% solids
indirect contact evaporator	-	newer recovery furnaces (after 1965) concentrate the black liquor solids from 55% solids to 65% solids with an indirect contact evaporator (also called a low-odour boiler)
foul condensate	-	process condensate from multiple effect evaporators that is more contaminated and generally must be stripped before reuse
green liquor	-	smelt from recovery boiler is dissolved to form green liquor which is subsequently converted to white liquor for reuse in digesters
larry car	-	vehicle that runs on rails along top of coke oven used to remove coke oven lids and load coal into coke ovens
leveller boot	-	a sealing device used to prevent emissions when leveller bar is pushed into coke oven through chuck door
levelling bar	-	bar inserted through chuck door used to level the coal during charging of coke oven
lignin	-	a naturally occurring highly polymerized substance which cements wood fibres together
luting	-	material (sodium silicate) used to seal or around coke oven doors and lids
multiple effect evaporator	-	weak black liquor from the brownstock washers is concentrated from approximately 15% solids to 55% solids in the multiple effect evaporator

pH	-	measure of the hydrogen ion concentration and the degree of acidity or alkalinity on a scale ranging from 0-14. neutral is 7.0 with 7.0-0 being increasingly acid and 7.0-14 being increasingly alkaline
power boiler	-	boiler which supplies heat for steam generation generally by burning hog fuel (wood waste)
pusher side	-	side of coke oven from which the finished coke is pushed (see coke side)
recausticizing	-	conversion of sodium carbonate (Na_2CO_3) into active sodium hydroxide (NaOH) and removal of impurities introduced from recovery furnace and lime kiln. Operation includes smelt dissolving tank, green liquor clarifier, slaker, white liquor clarifier, lime mud washing and calcining ("reburning") of lime mud to regenerate lime
recovery boiler	-	boiler/furnace which recovers inorganic chemicals in a molten form and supplies heat for steam generation
slag	-	limestone is used to remove impurities from the iron during processing, forming slag
slaker	-	vessel in which green liquor and reburned lime are combined to form white liquor
smelt	-	inorganic chemicals obtained in a molten form from the recovery furnace
standpipes	-	vertical pipes that collect off-gas from coke oven (where steam ejector is installed)
white liquor	-	cooking liquor used to separate wood fibres

weak wash	-	from lime mud and dregs washing

APPENDIX A:
EQUIPMENT SUPPLIERS

APPENDIX A: EQUIPMENT SUPPLIERS

Boiler Suppliers:

ABB Combustion
Andrew Jones
Ottawa
(613) 560-4442

Babcock & Wilcox
Brian Stone
Cambridge
(519) 621-2130

Gotavertaken
Bo Osearsson
Charlotte, NC
(704) 541-1453

Ahlstram
Ivan Pauldy
Montreal
(514) 383-7760

Black Liquor Oxidation:

MoDo Chemetics
Larry Tench
Vancouver
(604) 734-1200

A.H. Lundberg
Bruce Der
Vancouver
(604) 273-5204

Air Products Canada Ltd.
Brampton
(905) 791-2530

Dedicated Incinerators:

MoDo Chemetics
Lary Tech
Vancouver, BC
(604) 734-1200

A.H. Lundberg
Bruce Der
Vancouver, BC
(604) 273-5204

Lime Mud Washing:

EIMCO
John Crane
Mississauga
(905) 625-6070

Fuller-F.L. Smidth
Don Brown
Scarborough
(416) 284-8200

GL&V Ontario
Bernard Therrien
Coquitlam, BC
(604) 942-4377

Ahlstrom
Matti Lankinen
Roswell Georgia
(404) 640-2504

Non-Condensible Gas Systems:

MoDo Chemetics
Larry Tech
Vancouver, BC
(604) 734-1200

A.H. Lundberg
Bruce Der
Vancouver, BC
(604) 273-5204

Scrubber Suppliers:

Air Pol Inc.
Murray Borenstein
Teterboro, NJ
(201) 288-7070

Ceilcote Canada Air Pollution Control
Myron Krywonis
Mississauga, Ontario
(905) 795-0520

Turbotak Canada Inc.
Edward Spinke
Waterloo, Ontario
(519) 885-5513

Watson Process Systems
Frank Watson
Markham, Ontario
(905) 475-2511

Smelt Dissolving Tank Scrubber:

Air Pol Inc.
Murray Borenstein
Teterboro, NJ
(201) 288-7070

Turbotak Canada Inc.
Edward Spinke
Waterloo, Ontario
(519) 885-5513

The Turbotak scrubbing system is protected by various patents.

APPENDIX B:
PULP MILL DISPERSION MODELLING DETAILS

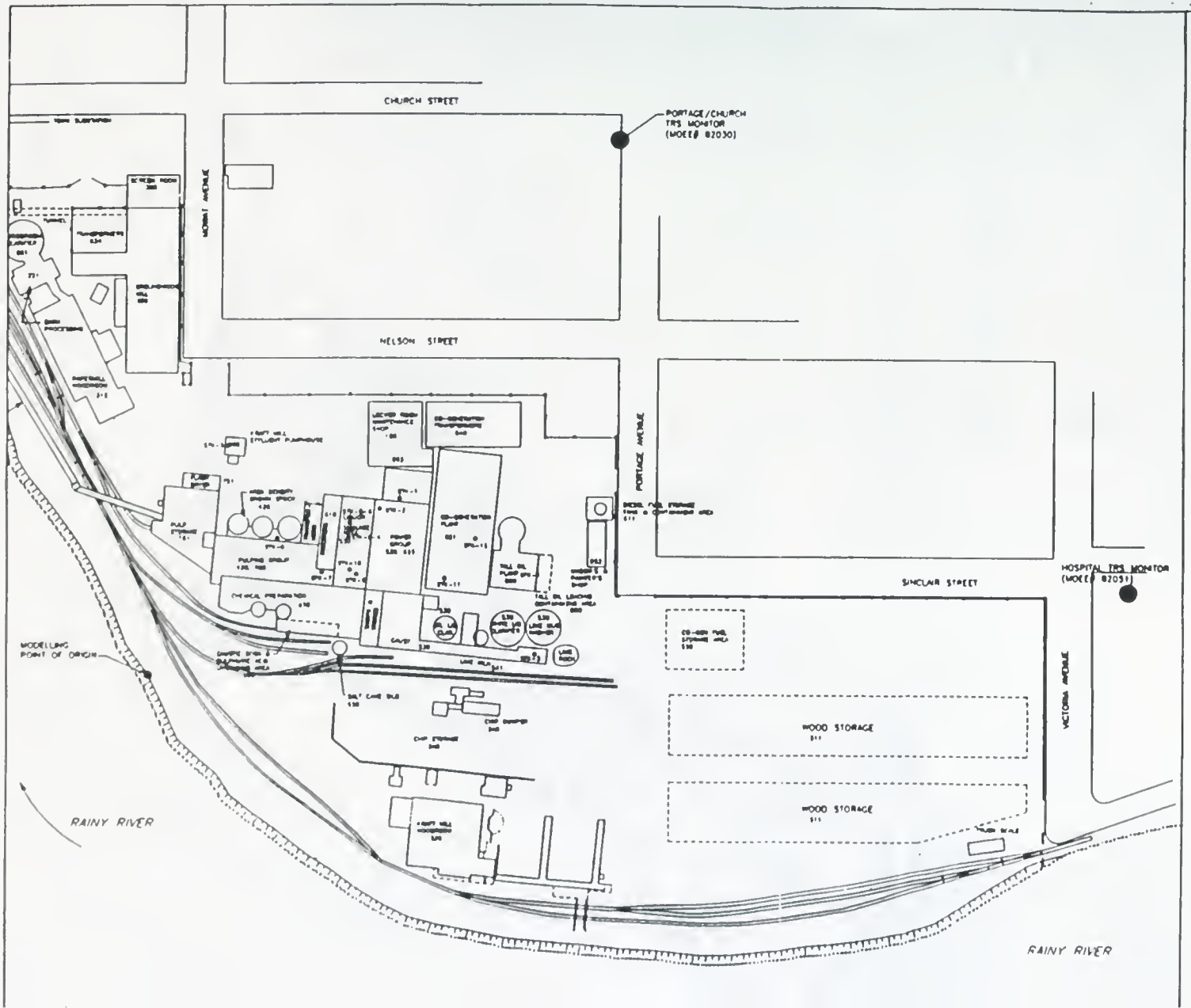


FIGURE 1.1

MILL SITE PLAN
BOISE CASCADE CANADA LTD.

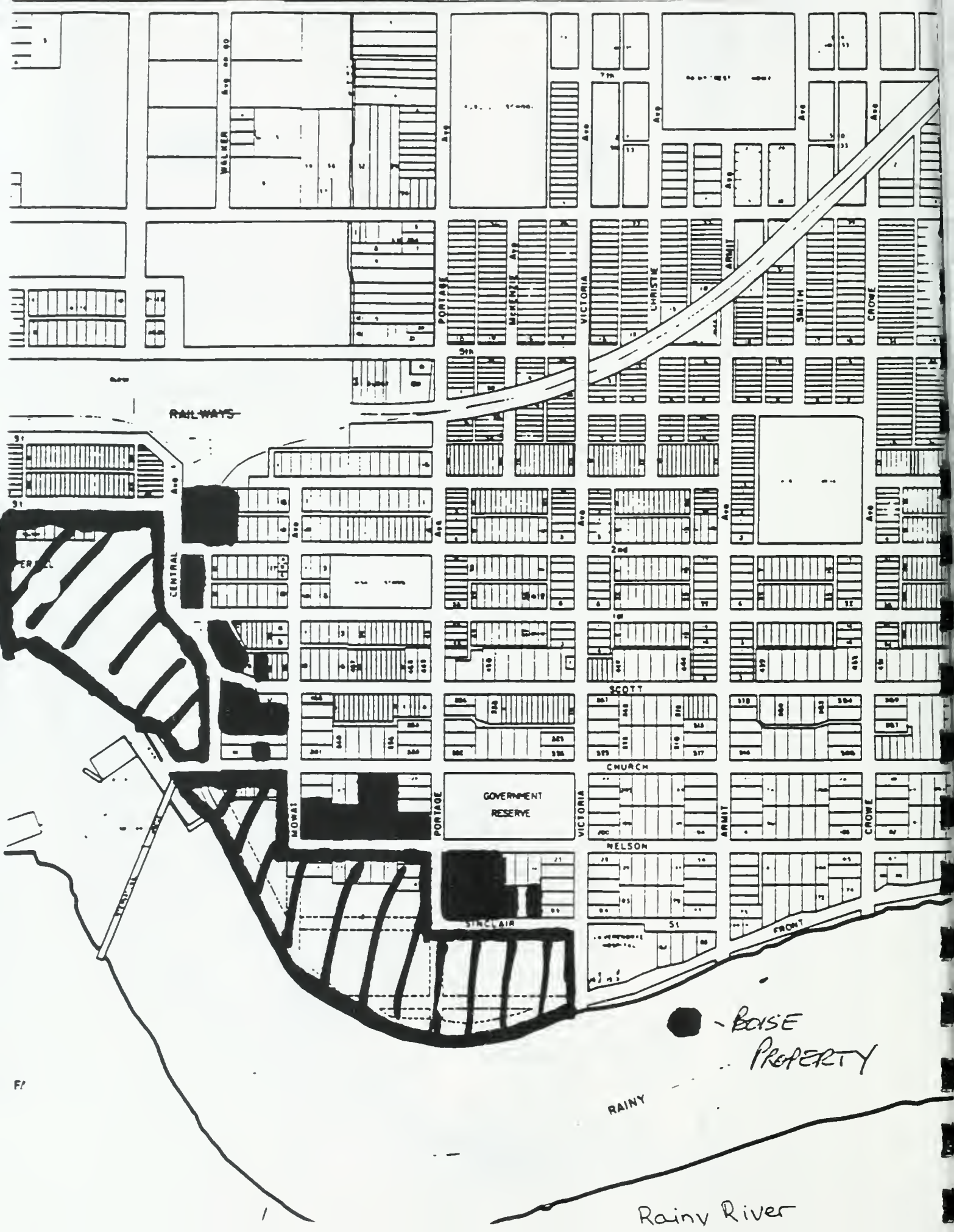
LEGEND

MOEE MONITOR LOCATION

N

40 0 40 80 120 metres

SCALE 1:2000


WALKER
PORTAGE
MCKENZIE
VICTORIA
CHRISTIE
ARMIT
SMITH
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RAILWAYS
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NELSON
MOWAT
GOVERNMENT RESERVE
SINCLAIR
FRONT
BOISE PROPERTY
RAINY
Rainy River

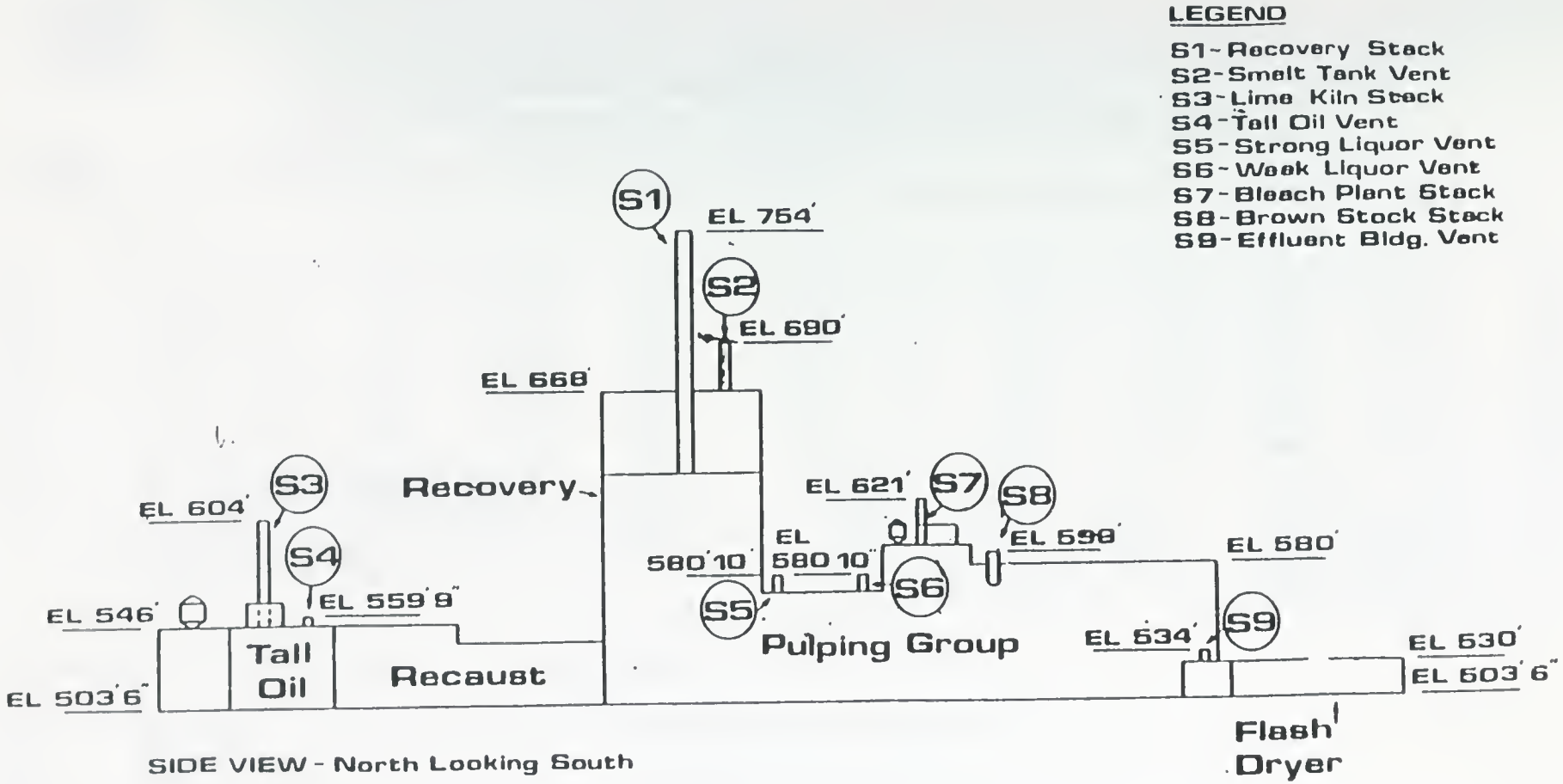


FIGURE 1

SIDE VIEW OF MILL WITH SAMPLING LOCATIONS

Boise Cascade

TABLE 4

POINT OF IMPINGEMENT COMPARISON

POI CONCETRATIONS (µg/m3)

DIST* (m)	EFFL PUMP HOUSE	BROWN STOCK WASHER	WEAK BLACK LIQUOR	STRONG BLACK LIQUOR	IMPOUND TANK	BLEACH PLANT SCRUB	RECOVERY BOILER STACK	SMELT DISSOLV TANK	LIME KILN	TALL OIL SCRUB	CLARIFY VENTS**
0	30.28	4.40	0.25	0.61	2.07	3.40	0.00	6.52	0.60	0.69	5.25
500	3.27	1.39	0.06	0.15	0.50	0.94	0.05	2.49	1.91	0.16	0.71
1000	1.37	0.73	0.03	0.07	0.25	0.50	0.14	1.49	1.75	0.07	0.31
2000	0.52	0.32	0.01	0.03	0.10	0.22	0.16	0.76	1.04	0.03	0.13
3000	0.29	0.19	0.01	0.02	0.06	0.13	0.14	0.48	0.66	0.02	0.07
4000	0.19	0.13	0.00	0.01	0.04	0.09	0.11	0.33	0.46	0.01	0.05

* Property line located at the north edge of the parking lot adjacent to the recovery boiler area.

** Property line located 150 m north of the clarifier building.

Table 3.1

Source Characteristics used in Air Dispersion Modelling

Source No:	Source Description	Coordinates (m)		Stack Height (m)	Diameter (m)	Exit Velocity (m/s)	Exit Temp. (°K)	TRS (g/s)
		x	y					
STK-1	Recovery Boiler	128.3	89.6	76.3	2.79	19.8	478.8	0.0389
STK-2	Smelt Dissolving Tank	118	84.3	56.8	1.52	5.9	340.6	0.195
STK-3	Lime Kiln	198.3	10.9	30.6	1.52	10.2	347.6	0.203
STK-4	Tall Oil Plant	188.5	52.1	17.1	0.46	3.2	315	0.00508
STK-5	Effluent Pump House	40.3	116.5	9.3	0.43	0.7	299	0.0493
STK-6	Brown Stock Washers	65.9	69.4	28.8	1.30	15.4	306.3	0.133
STK-7	Bleach Plant	88.9	52.2	35.8	1.07	13.3	318.4	0.0325
STK-8-A	Weak Black Liquor Storage Tanks	102.3	69.8	23.6	0.28	3.6	313	0.00334
STK-8-B	Weak Black Liquor Storage Tanks	102.7	77.2	23.6	0.28	3.6	313	0.00334
STK-9	Strong Black Liquor Storage Tanks	103.2	53.5	23.6	0.25	1.0	327	0.00454
STK-10	Impounding Tank	106.3	51.2	23.6	1.20	0.3	300.6	0.299

Bldg. No.	Building Names	Bldg. Heights (m)
Bldg.-1	Lime Kiln	12.4
Bldg.-2	Shops&Stores	12.0*
Bldg.-3	Power Group	50.1
Bldg.-4	Co-Generation Plant	34.7
Bldg.-5	Locker Room/Maintenance Shop	12.0*
Bldg.-6	Co-Generation Transformers	12.0*
Bldg.-7	Liquor Tankage Area	16.1
Bldg.-8	Digesters	23.3
Bldg.-9	Chemical Preparation	26.0
Bldg.-10	Pulping Group	23.3
Bldg.-11	Pulp Storage	8.1
Bldg.-12	Tall Oil Plant	12.4

Note: * - Assumed values.

BOISE CASCADE CANADA LTD.
FORT FRANCIS, ONTARIO

TABLE 4

IMET PROJECT 1701
JULY 1989

POINT OF IMPINGEMENT CONCENTRATIONS

(ug/m3)

DISTANCE FROM PROPERTY LINE (m)	WEAK BLK. LIQ.	STRONG BLK. LIQ.	BROWN STOCK	BLEACH PLANT	RECOVER BOILER	SMELT TANK	LIME KILN	TALL OIL	EFFLUENT PUMP
-100	0.47	1.27	0.95	3.03	0	47.3	0	6.27	7.21
-90	0.44	1.19	0.92	2.8	0	44.98	0	5.85	6.29
-80	0.42	1.12	0.87	2.61	0	42.91	0	5.47	5.55
-70	0.39	1.06	0.82	2.44	0	41.04	0	5.13	4.93
-60	0.37	1	0.78	2.3	0	39.34	0.02	4.83	4.41
-50	0.35	0.95	0.74	2.17	0	37.79	0.05	4.55	3.97
-40	0.33	0.9	0.71	2.06	0	36.37	0.11	4.29	3.59
-30	0.32	0.86	0.68	1.96	0	35.08	0.22	4.05	3.27
-20	0.3	0.82	0.65	1.86	0	33.85	0.39	3.84	2.98
-10	0.29	0.78	0.62	1.78	0	32.73	0.61	3.64	2.73
0	0.28	0.74	0.6	1.7	0	31.69	0.9	3.45	2.52
10	0.26	0.71	0.57	1.63	0	30.72	1.24	3.28	2.32
20	0.25	0.68	0.55	1.56	0	29.81	1.63	3.12	2.15
30	0.24	0.66	0.53	1.5	0	28.96	2.07	2.98	2
40	0.23	0.63	0.51	1.45	0	28.16	2.53	2.84	1.86
50	0.22	0.61	0.49	1.4	0	27.4	3.02	2.71	1.74
60	0.22	0.58	0.48	1.35	0	26.68	3.52	2.59	1.62
70	0.21	0.56	0.46	1.3	0	26.01	4.04	2.48	1.52
80	0.2	0.54	0.44	1.26	0	25.37	4.55	2.38	1.43
90	0.19	0.52	0.43	1.22	0	24.18	5.05	2.28	1.35
100	0.19	0.5	0.42	1.18	0	23.63	5.55	2.19	1.27
110	0.18	0.49	0.4	1.14	0	23.1	6.03	2.1	1.2
120	0.17	0.47	0.39	1.11	0	22.6	6.51	2.02	1.14

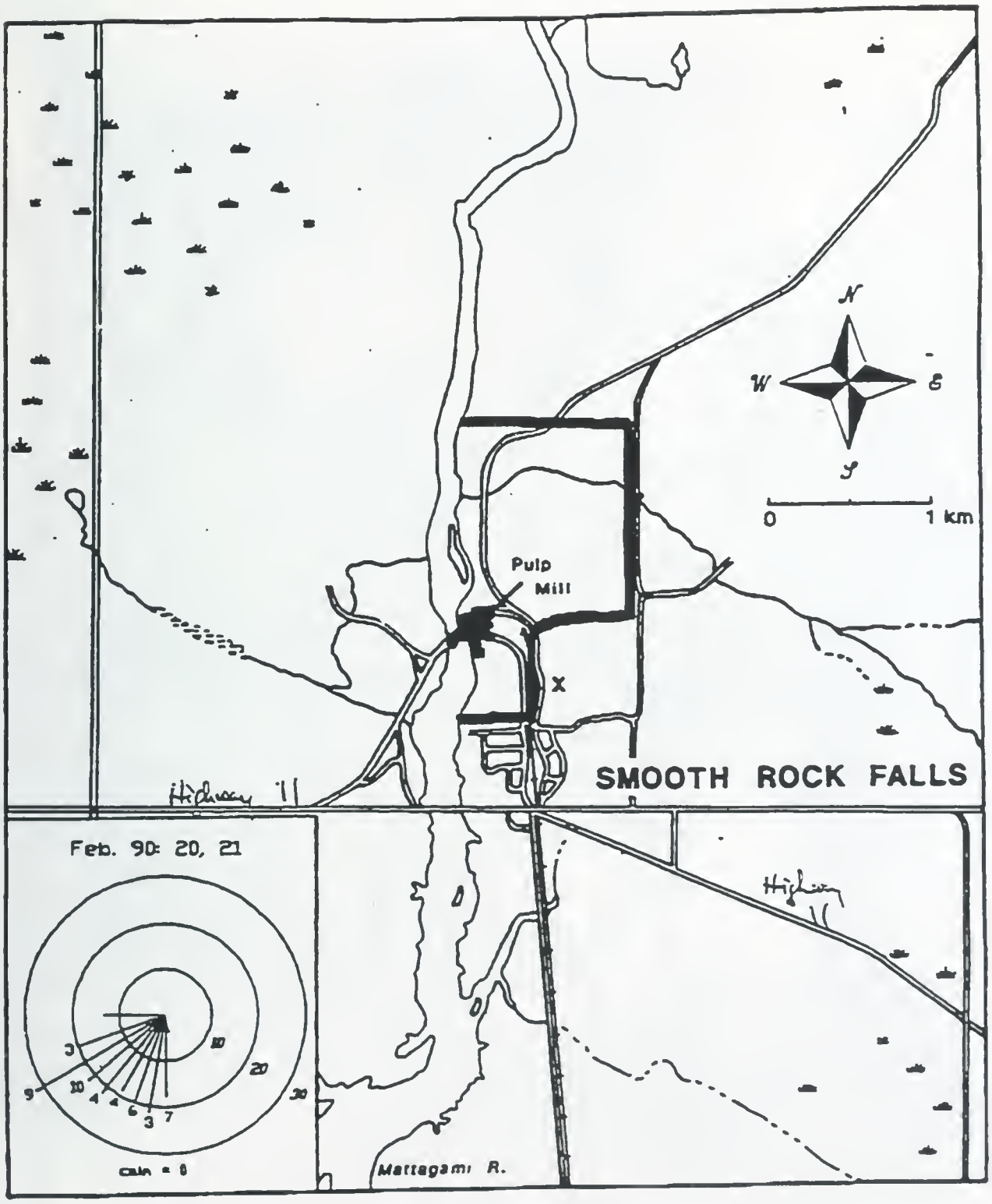
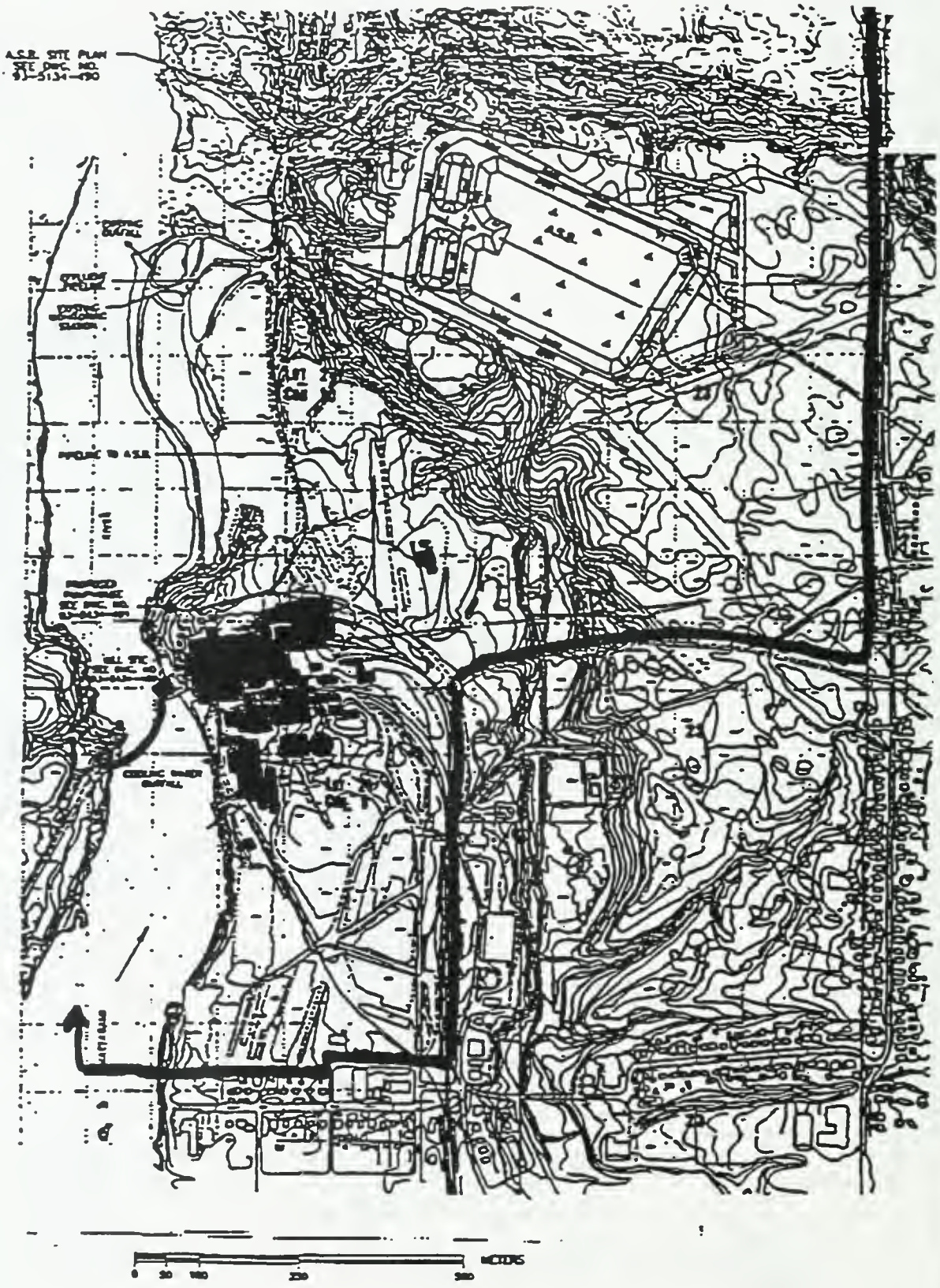


Figure 3.ii. Smooth Rock Falls wind speed and direction, February 20 & 21, 1990.



Malette – Smooth Rock Falls

FIGURE 2-1 **Malette Kraft Pulp and Power Source Locations**

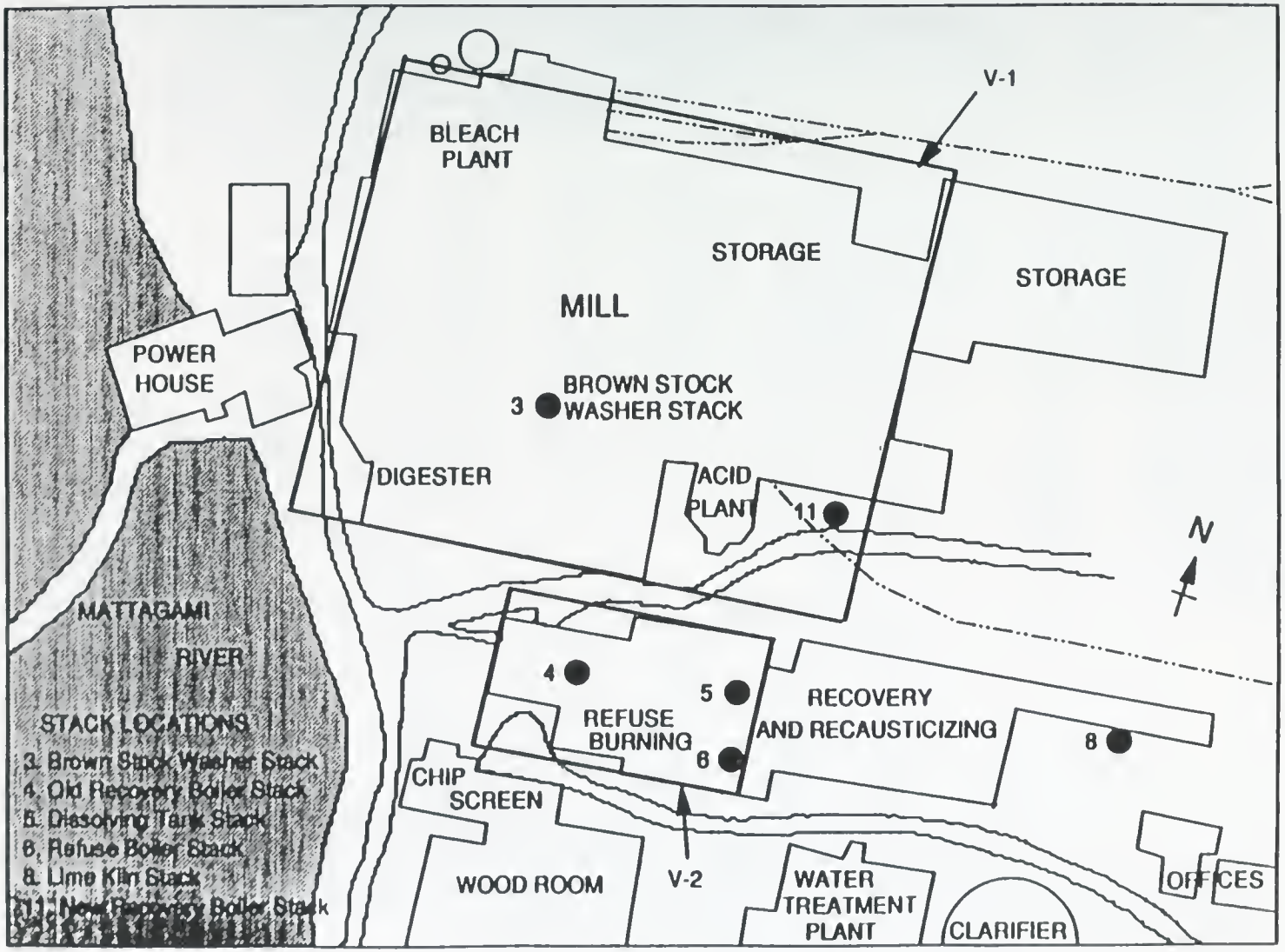


TABLE 2-1 **Stack Parameters and Emission Rates for Malette Pulp & Power**

EMISSION PARAMETERS		BROWN STOCK UNITS 1 & 2	BROWN STOCK UNIT #3 (1)	OLD RECOVERY BOILER	SMELT DISSOLVING TANK	REFUSE BOILER	LIME KILN (2) With Scrubber	LIME KILN (6) With ESP	NEW RECOVERY BOILER	
STACK X,Y COORD (m,m)		(14,64)	(14,-78)	(0,0)	(46,-1)	(47,-17)	(140,6)	(140,6)	(57,43)	
STACK HEIGHT (m)		25	25	47	36	52	33	33	68	
STACK DIAM (m)		0.91	0.91	2.13	1.22	1.68	0.91	0.91	2.44	
EXIT GAS TEMP (C)		0.6	0.6	55.5	81.5	67.7	74.7	168.7	173.0	
EXIT GAS VELOCITY (m/s)		19.1	19.1	18.9	4.9	7.9	11.9	14.1	14.4	
BUILDING WIDTH (m)		125	125	44	44	44	-	-	-	
BUILDING LENGTH (m)		122	122	65	65	65	-	-	-	
BUILDING HEIGHT (m)		25	25	41	31	41	-	-	-	
BUILDING X,Y COORD (m,m)		(11,92)	(11,92)	(23,6)	(23,8)	(23,6)	-	-	-	
EMISSION RATES (g/s)										
SCENARIO	POLL(3)									TOTAL
PAST (4)	PMT	0.00	0.00	7.93	0.39	2.33	1.70	-	-	12.4
	TRS	0.57	1.91	6.52	0.38	0.00	0.02	-	-	9.4
PRE-1993 (5)	PMT	0.00	0.00	6.07	0.29	1.66	1.78	-	-	9.8
	TRS	0.06	0.03	1.56	0.21	0.00	0.99	-	-	2.9
	NOx	0.00	0.00	4.50	0.05	2.72	1.44	-	-	8.7
	CO	0.00	0.00	0.52	0.18	34.00	1.70	-	-	36.4
	SO2	0.00	0.00	0.41	4.84	0.00	6.53	-	-	11.8
1993- (5)	PMT	0.00	0.00	6.06	0.29	1.66	-	0.11	1.18	9.3
	TRS	0.06	0.03	1.56	0.21	0.00	-	0.05	0.31	2.2
	NOx	0.00	0.00	4.50	0.05	2.72	-	1.44	4.06	12.8
	CO	0.00	0.00	0.52	0.18	34.00	-	0.02	5.07	39.8
	SO2	0.00	0.00	0.41	4.84	0.00	-	N/A	5.30	10.5

(1) Brown Stock Unit #3 is assumed to be 50% of combined Units #1 & #2 for Pre-1993 and 1993 onwards.
(2) Values shown are for wet scrubber prior to December 1992.
(3) NOx expressed as NO and TRS expressed as H2S.
(4) Data from IMET 1990 report.
(5) Data from ATS 1992 and 1993 reports.
(6) NOx, CO and SO2 were not test on the Lime Kiln with ESP. Emissions represent AP-42 values.

Date: 14-Feb-93

CONCORD ENVIRONMENTAL

TABLE 3-2

Regulation 346 - Maximum Contaminant Concentrations Near Eastern Property Boundary (1)

SCENARIO	POLL	MAX CONC (µg/m3)	% OF STANDARD(2)	CONTRIBUTION FROM STACKS (µg/m3)							DIST (3) (m)	STABILITY	WIND SPEED (m/s)	WIND DIRN
				BROWN STOCK WASHERS	OLD RECOVERY BOILER	SMELT DISSOLVING TANK	REFUSE BOILER	LIME KILN	NEW RECOVERY BOILER	LIME KILN with ESP				
PAST	PMT	327	327	0	243	12	71	1	-	-	400	D	6.74	W
	TRS	231	577	19	200	11	0	0	-	-	400	D	6.74	W
PRE 1993	PMT	247	247	0	186	9	51	1	-	-	400	D	6.74	W
	SO2	223	27	0	6	75	0	142	-	-	850	D	2.24	W
	NO2	335	67	0	207	2	125	1	-	-	400	D	6.74	W
	CO	1064	18	0	16	6	1042	1	-	-	400	D	6.74	W
	TRS	55	139	1	48	6	0	1	-	-	400	D	6.74	W
1993 -	PMT	246	246	0	185	9	51	-	0	1	400	D	9.74	W
	SO2	161	19	0	13	148	0	-	0	0	400	D	2.24	W
	NO2	335	67	0	207	2	125	-	0	1	400	D	9.74	W
	CO	1064	18	0	16	6	1042	-	0	0	400	D	9.24	W
	TRS	55	137	1	48	6	0	-	0	0	400	D	9.74	W
1993 - (4)	PMT	60	60	0	0	9	51	-	0	0	400	D	14.24	W
	SO2	148	18	0	0	148	0	-	0	0	400	D	18.33	W
	NO2	128	26	0	0	2	125	-	0	1	400	D	10.24	W
	CO	1048	17	0	0	6	1042	-	0	0	400	D	10.24	W
	TRS	7	18	0	5	1	0	-	0	0	1150	C	2.24	W

(1) Eastern boundary is at about 400 m from the old recovery boiler.

(2) 1/2 h Standards:

PMT =	100	µg/m3
SO2 =	830	µg/m3
NO2 =	500	µg/m3
CO =	6000	µg/m3
TRS =	40	µg/m3

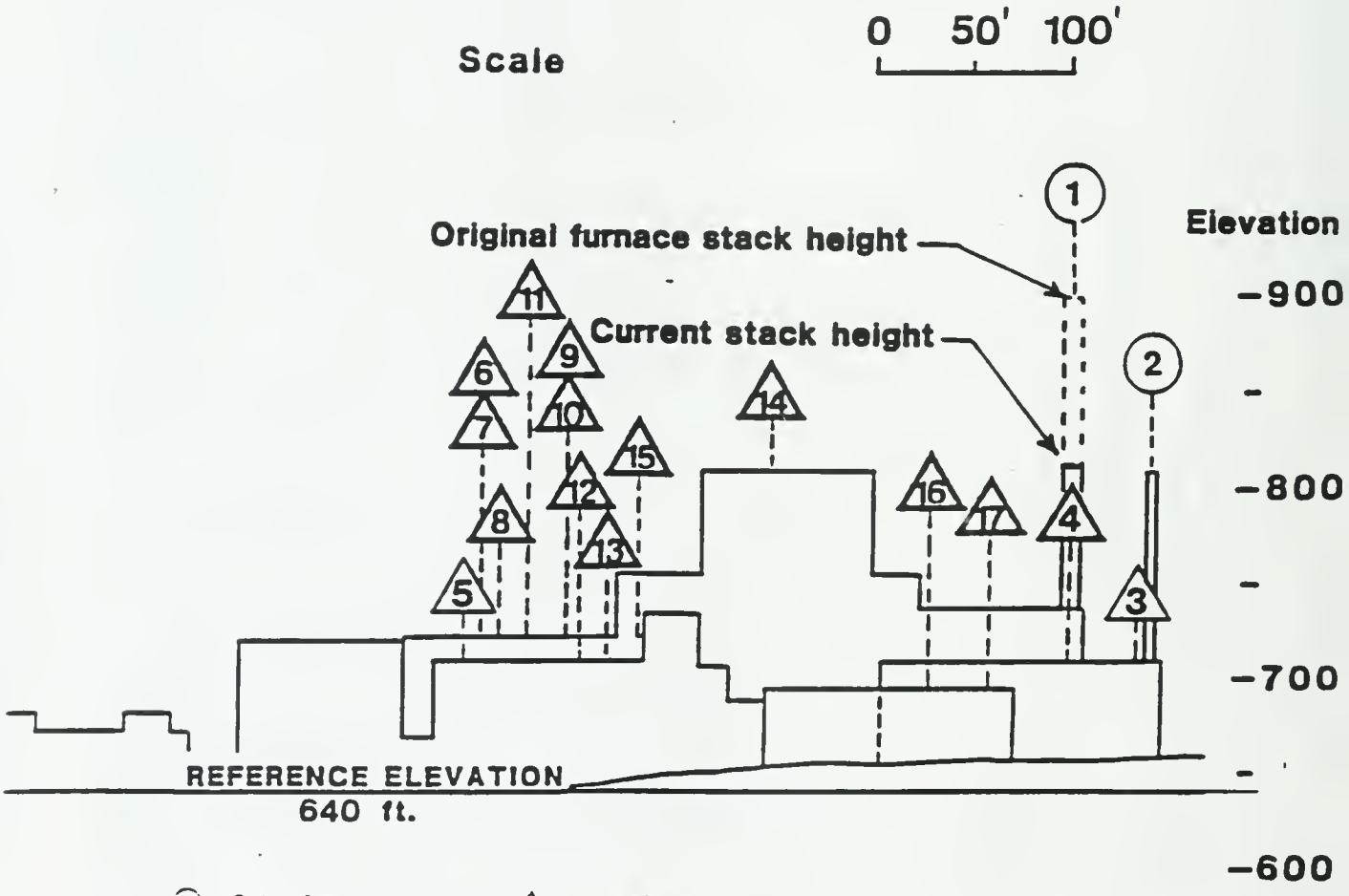
(3) Distance from Old Recovery Boiler.

(4) Stack height of Old Recovery Boiler at 61 m

CONCORD ENVIRONMENTAL

Malette

FIGURE 1 RED ROCK KRAFTMILL PROFILE AS VIEWED FROM THE NW



No.	Description
1	No. 3 Recovery
2	No. 2 Lime Kiln
3	Green Liquor Clarifier Vent
4	Lime Mud Filter Hood Vent
5	Soft Stock Washer Foam Tank Vent
6	No.s 6 & 6 Hardstock Washer Hood Vent
7	No. 7 Hardstock Washer Hood Vent
8	Hardstock Washer Foam Tank Vent
9	No.s 8 & 9 M&D Washer Hood Vent

No.	Description
10	No. 10 M&D Washer Hood Vent
11	M&D Washer Foam Tank Vent
12	No. 2 Softstock Washer Hood Vent
13	No. 1 Softstock Washer Hood Vent
14	No. 3 Recovery Dissolving Tank Vent
15	Turpentine Decanter Vent
16	No. 1 Causticizer Vent
17	No. 2 Causticizer Vent

FIG. 2 PLAN VIEW OF THE RED ROCK MILL SHOWING TRS EMISSION SOURCES AND MILL PROPERTY LINE

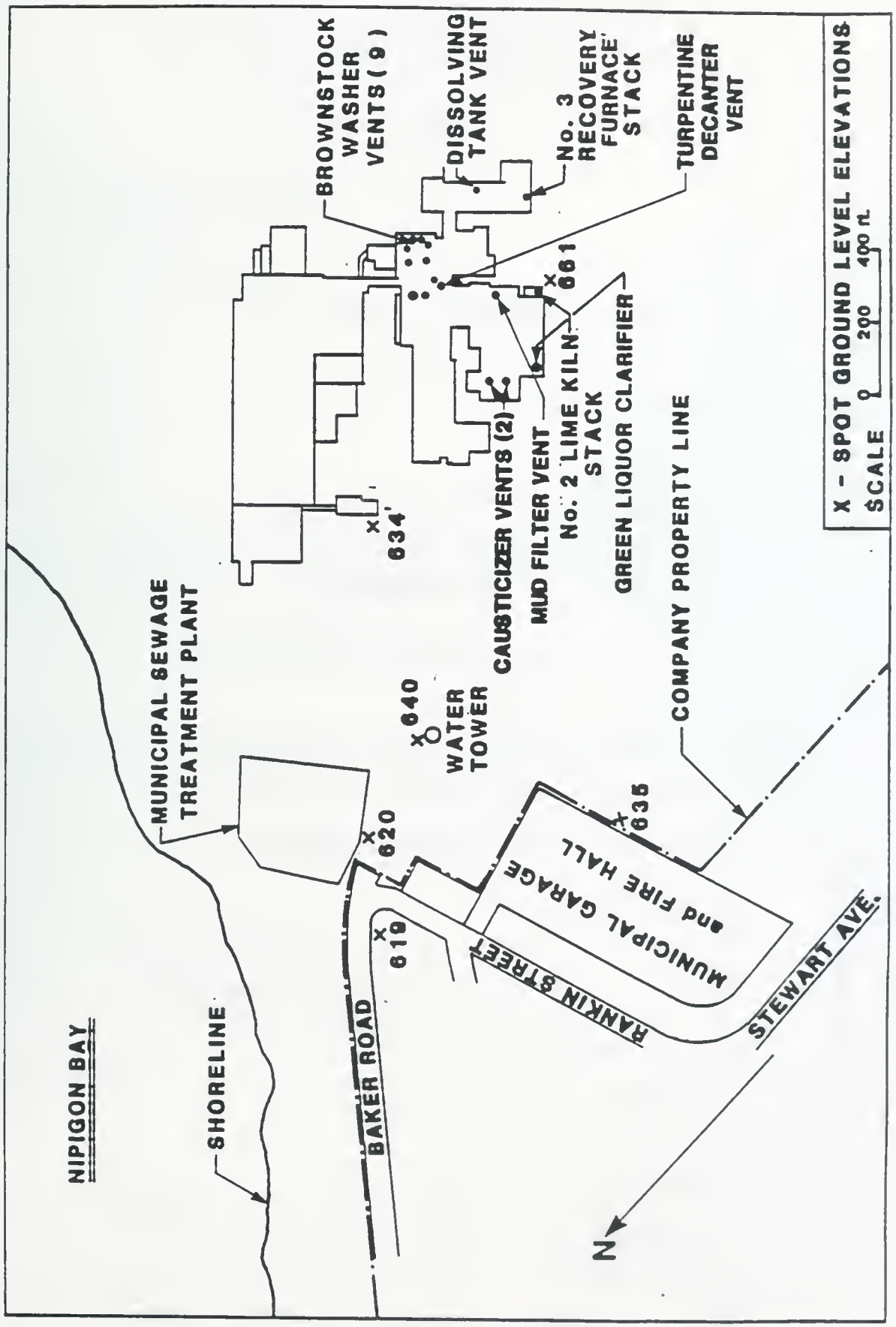


FIG. 3 TRS DISPERSION AVERAGE EMISSIONS

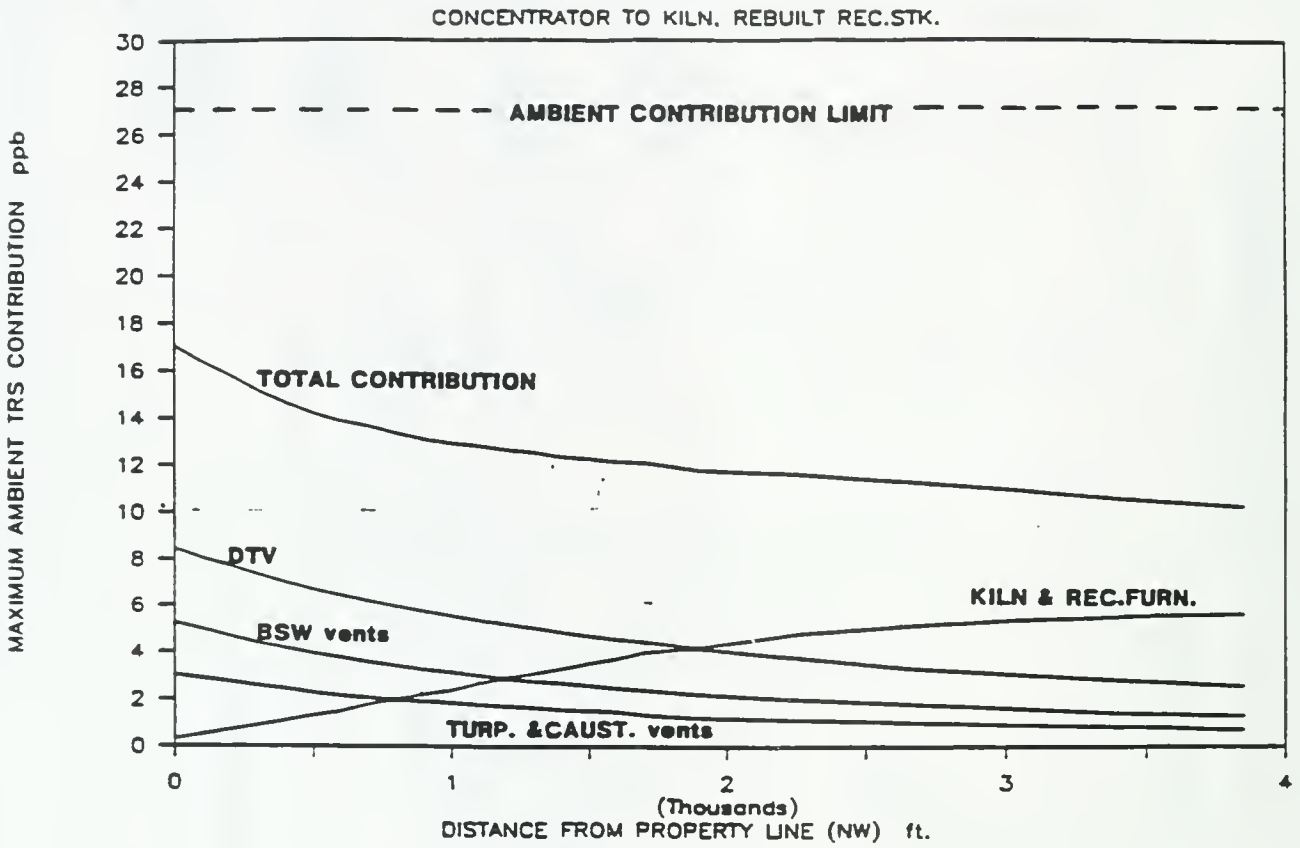


FIG. 4 TRS DISPERSION AVERAGE EMISSIONS

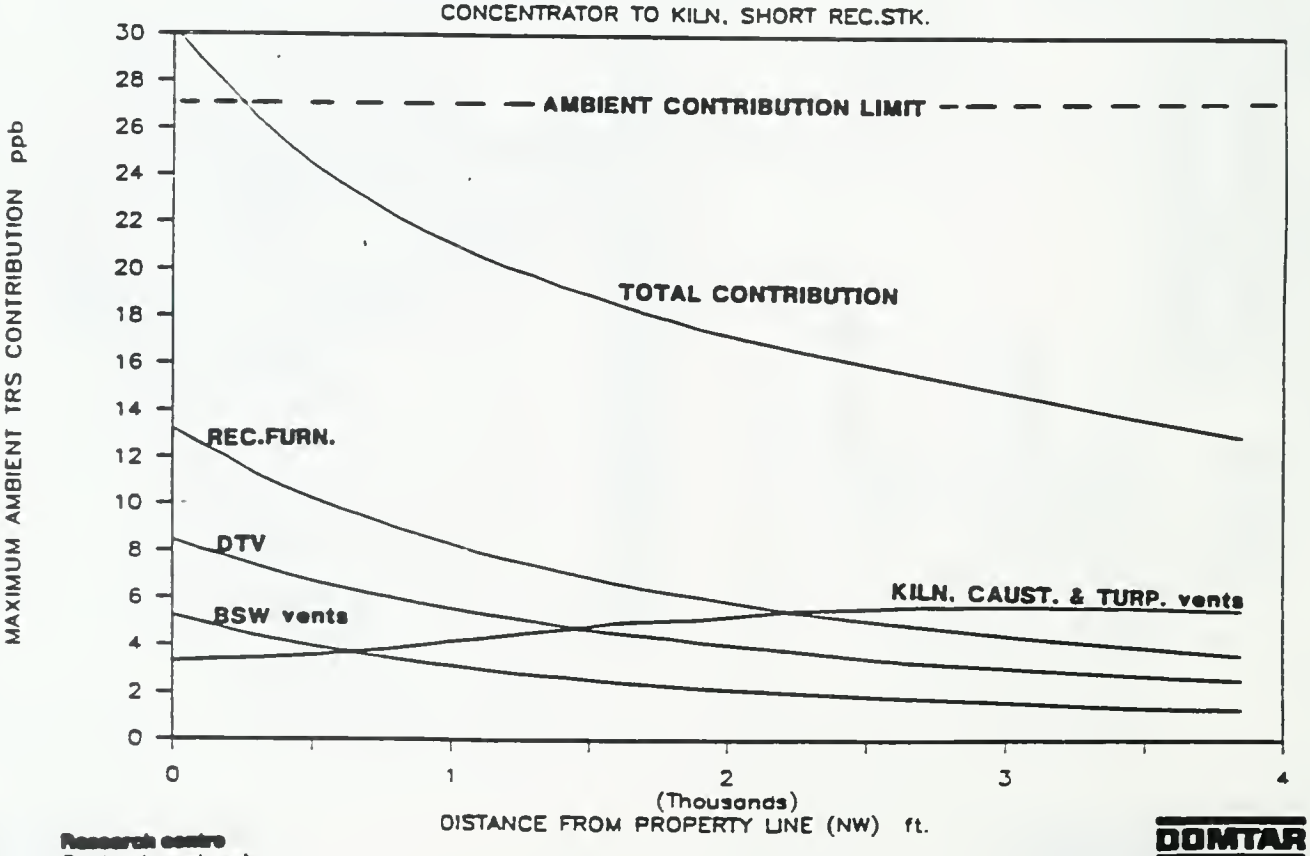


FIG. 5 TRS DISPERSION AVERAGE EMISSIONS

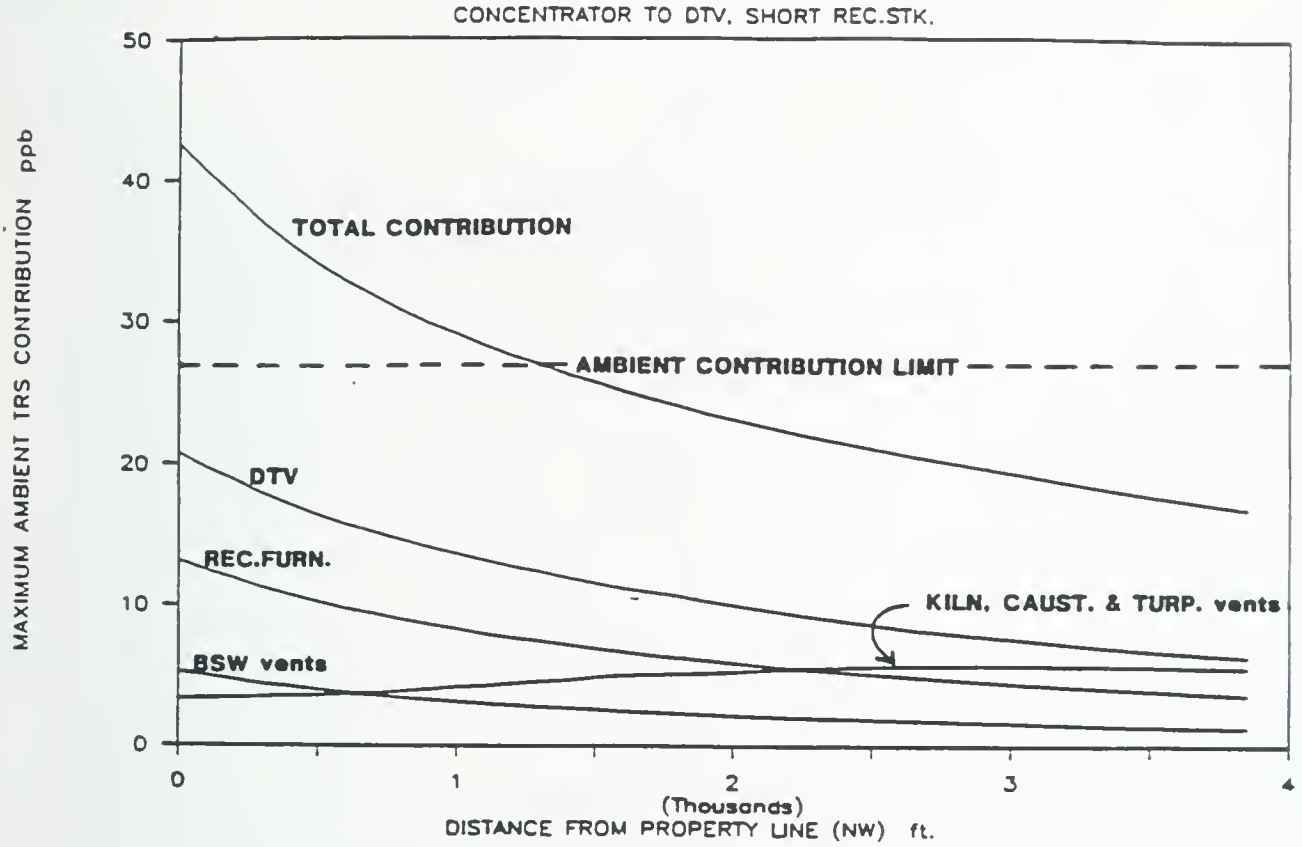
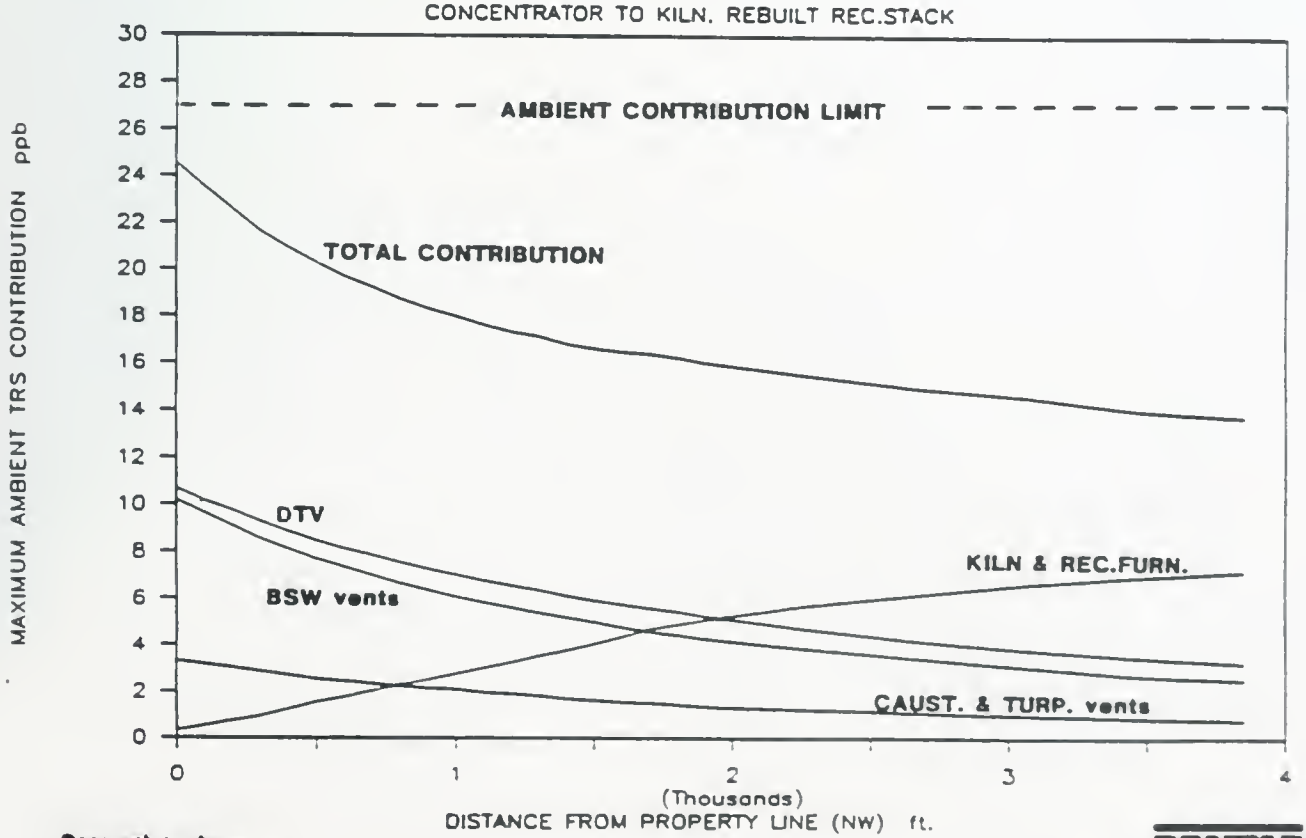


FIG. 6 TRS DISPERSION MAXIMUM EMISSIONS



APPENDIX C:
DETAILED CONTROL COSTS
FOR PULP MILLS

Table C.1
Combustion of emissions from brownstock foam tank, weak black liquor storage tank (Enclosures not required) in existing device - 500 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$258,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$124,000
Direct installation cost	0.5*PEC	$62,000
Engineering	0.1*PEC	$12,400
Construction overhead	0.05*PEC	$6,200
Contractor Fees	0.1*PEC	$12,400
Start-up	0.02*PEC	$2,500
Performance test	0.01*PEC	$1,200
Contingencies	0.3*PEC	$37,200
Total Capital Cost	**2.08*PEC**	**$258,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Cost	5% of TCC	$12,900
Overhead (60% of labour and maintenance costs)		$7,700
Utilities (fuel)	*	$0
Utilities (electricity)	$0.059/kwh *	$6,700
Administrative	2% of TCC	$5,200
Property taxes	1% of TCC	$2,600
Insurance	1% of TCC	$2,600
Operating and Maintenance Cost	Sum of above	**$38,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$42,000
Total Annualized Cost	O&M + capital recovery	**$80,000**

* U.S.EPA 1993a

Notes:
Utilities
electricity (kWh/y) - (U.S.EPA 1993a) 114297 10% of total

Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$66,309
purchased equipment cost stainless steel	$86,202
retrofit cost factor (estimated from U.S.EPA 1993a)	1.44
purchased equipment cost - stainless steel/retrofit factor	$124,000

Electricity is the only utility cost considered (U.S.EPA 1993a)
It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.2
Combustion of emissions from brownstock foam tank, weak black liquor storage tank (Enclosures not required) in existing device - 1000 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$424,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$203,800
Direct installation cost	0.5*PEC	$101,900
Engineering	0.1*PEC	$20,400
Construction overhead	0.05*PEC	$10,200
Contractor Fees	0.1*PEC	$20,400
Start-up	0.02*PEC	$4,100
Performance test	0.01*PEC	$2,000
Contingencies	0.3*PEC	$61,100
Total Capital Cost	**2.08*PEC**	**$424,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Cost	5% of TCC	$21,200
Overhead (60% of labour and maintenance costs)		$12,700
Utilities (fuel)	*	$0
Utilities (electricity)	$0.059/kwh *	$6,700
Administrative	2% of TCC	$8,500
Property taxes	1% of TCC	$4,200
Insurance	1% of TCC	$4,200
Operating and Maintenance Cost (O&M)	Sum of above	**$58,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$69,000
Total Annualized Cost	O&M + capital recovery	**$127,000**

* U.S.EPA 1993a

Notes:
Utilities
electricity (kWh/y) - (U.S.EPA 1993a) 114297 10% of total

Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$108,982
purchased equipment cost stainless steel	$141,677
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$203,800

Electricity is the only utility cost considered (U.S.EPA 1993a)
It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.3
Combustion of emissions from brownstock foam tank, weak black liquor storage tank (Enclosures not required) in existing device - 1500 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$621,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$298,600
Direct installation cost	0.5*PEC	$149,300
Engineering	0.1*PEC	$29,900
Construction overhead	0.05*PEC	$14,900
Contractor Fees	0.1*PEC	$29,900
Start-up	0.02*PEC	$6,000
Performance test	0.01*PEC	$3,000
Contingencies	0.3*PEC	$89,600
Total Capital Cost	**2.08*PEC**	**$621,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Cost	5% of TCC	$31,100
Overhead (60% of labour and maintenance costs)		$18,700
Utilities (fuel)	*	$0
Utilities (electricity)	$0.059/kwh *	$6,700
Administrative	2% of TCC	$12,400
Property taxes	1% of TCC	$6,200
Insurance	1% of TCC	$6,200
Operating and Maintenance Cost	Sum of above	**$81,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$101,000
Total Annualized Cost	O&M + capital recovery	**$182,000**

* U.S.EPA 1993a

Notes:
Utilities
electricity (kWh/y) - (U.S.EPA 1993a) 114297 10% of total

Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$159,676
purchased equipment cost stainless steel	$207,579
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$298,600

Electricity is the only utility cost considered (U.S.EPA 1993a)
It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.4
Combustion of emissions from brownstock washers, knotter, deckers/screens (Enclosures Required) in Existing Device - 500 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital cost Reported by U.S.EPA 1993 a and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,515,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$728,400
Direct installation cost	0.5*PEC	$364,200
Engineering	0.1*PEC	$72,800
Construction overhead	0.05*PEC	$36,400
Contractor Fees	0.1*PEC	$72,800
Start-up	0.02*PEC	$14,600
Performance test	0.01*PEC	$7,300
Contingencies	0.3*PEC	$218,500
Total Capital Cost	**2.08*PEC**	**$1,515,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Cost	5% of TCC	$75,800
Overhead (60% of labour and maintenance costs)		$45,500
Utilities (fuel)	*	$0
Utilities (electricity)	$0.059/kwh *	$60,700
Administrative	2% of TCC	$30,300
Property taxes	1% of TCC	$15,200
Insurance	1% of TCC	$15,200
Operating and Maintenance Cost (O&M)	Sum of above	**$243,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$247,000
Total Annualized Cost	O&M+Capital Recovery	**$490,000**

* U.S.EPA 1993a

Notes:
Utilities
electricity (kWh/y) - (U.S.EPA 1993a) 1028676 90% of total

Btu-kWh converstion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$389,512
purchased equipment cost stainless steel	$506,365
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$728,400

Electricity is the only utility cost considered (U.S.EPA 1993a)
It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.5
Combustion of emissions from brownstock washers, knotter, deckers/screens (Enclosures Required) in Existing Device - 1000 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital cost Reported by U.S.EPA 1993 a and corrected to ($Can 1994)
Combustion of emissions from brownstock washers, knotter, deckers/screens

Total Capital Cost (TCC)	$2,424,000

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,165,400
Direct installation cost	0.5*PEC	$582,700
Engineering	0.1*PEC	$116,500
Construction overhead	0.05*PEC	$58,300
Contractor Fees	0.1*PEC	$116,500
Start-up	0.02*PEC	$23,300
Performance test	0.01*PEC	$11,700
Contingencies	0.3*PEC	$349,600
Total Capital Cost	2.08*PEC	**$2,424,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Cost	5% of TCC	$121,200
Overhead (60% of labour and maintenance costs)		$72,700
Utilities (fuel)	*	$0
Utilities (electricity)	$0.059/kwh *	$60,700
Administrative	2% of TCC	$48,500
Property taxes	1% of TCC	$24,200
Insurance	1% of TCC	$24,200
Operating and Maintenance Cost (O&M)	Sum of above	**$352,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$395,000
Total Annualized Cost	O&M+Capital Recovery	**$747,000**

* U.S.EPA 1993a

Notes:
Utilities
electricity (kWh/y) - (U.S.EPA 1993a) 1028676 90% of total

Btu-kWh converstion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$623,198
purchased equipment cost stainless steel	$810,157
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$1,165,400

Electricity is the only utility cost considered (U.S.EPA 1993a)
It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.6
Combustion of emissions from brownstock washers, knotter, deckers/screens (Enclosures Required) in Existing Device - 1500 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital cost Reported by U.S.EPA 1993 a and corrected to ($Can 1994)
Combustion of emissions from brownstock washers, knotter, deckers/screens

Total Capital Cost (TCC)	**$3,182,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,529,800
Direct installation cost	0.5*PEC	$764,900
Engineering	0.1*PEC	$153,000
Construction overhead	0.05*PEC	$76,500
Contractor Fees	0.1*PEC	$153,000
Start-up	0.02*PEC	$30,600
Performance test	0.01*PEC	$15,300
Contingencies	0.3*PEC	$458,900
Total Capital Cost	**2.08*PEC**	**$3,182,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Cost	5% of TCC	$159,100
Overhead (60% of labour and maintenance costs)		$95,500
Utilities (fuel)	*	$0
Utilities (electricity)	$0.059/kwh *	$60,700
Administrative	2% of TCC	$63,600
Property taxes	1% of TCC	$31,800
Insurance	1% of TCC	$31,800
Operating and Maintenance Cost (O&M)	Sum of above	**$443,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$518,000
Total Annualized Cost	O&M+Capital Recovery	**$961,000**

* U.S.EPA 1993a

Notes:
Utilities
electricity (kWh/y) - (U.S.EPA 1993a) 1028676 90% of total

Btu-kWh converstion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$818,061
purchased equipment cost stainless steel	$1,063,479
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$1,529,800

Electricity is the only utility cost considered (U.S.EPA 1993a)
It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.7
Combustion of Emissions from Brownstock Washers (enclosures required)
In Existing Device - 1000 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell (1994)

Total Capital Cost (TCC)	**$3,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,442,300
Direct installation cost	0.5*PEC	$721,200
Engineering	0.1*PEC	$144,200
Construction overhead	0.05*PEC	$72,100
Contractor Fees	0.1*PEC	$144,200
Start-up	0.02*PEC	$28,800
Performance test	0.01*PEC	$14,400
Contingencies	0.3*PEC	$432,700
Total Capital Cost	**2.08*PEC**	**$3,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$150,000
Overhead (60% of labour and maintenance costs)		$103,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$60,700
Administrative	2% of TCC	$60,000
Property taxes	1% of TCC	$30,000
Insurance	1% of TCC	$30,000
Operating and Maintenance Cost (O&M)	Sum of above	**$457,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $488,000
Total Annualized Cost	O&M + capital recovery	**$945,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979) 0
electricity (kWh/y) - (U.S.EPA 1993a) 1028676 90% of total

Btu-kWh converstion factor 0.00029
stainless steel multiplier 1.3
purchased equipment cost carbon steel $771,270
purchased equipment cost stainless steel $1,002,651
retrofit cost factor (estimated) 1.44
purchased equipment cost - stainless steel/retrofit factor $1,442,300

Table C.8
Brown stock washer emission collection - destruction in recovery boiler - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and Corrected to ($Can 1994)

Total Capital Cost (TCC)	**$2,269,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,090,900
Direct installation cost	0.5*PEC	$545,500
Engineering	0.1*PEC	$109,100
Construction overhead	0.05*PEC	$54,500
Contractor Fees	0.1*PEC	$109,100
Start-up	0.02*PEC	$21,800
Performance test	0.01*PEC	$10,900
Contingencies	0.3*PEC	$327,300
Total Capital Cost	**2.08*PEC**	**$2,269,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$113,500
Overhead (60% of labour and maintenance costs)		$81,700
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$44,200
Administrative	2% of TCC	$45,400
Property taxes	1% of TCC	$22,700
Insurance	1% of TCC	$22,700
Operating and Maintenance Cost (O&M)	Sum of Above	**$353,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$369,000
Total Annualized Cost	O&M*capital recovery	**$722,000**

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	5376

Table C.9
Brown stock washer emission collection - destruction in recovery boiler - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and Corrected to ($Can 1994)

Total Capital Cost (TCC)	**$3,782,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,818,300
Direct installation cost	0.5*PEC	$909,200
Engineering	0.1*PEC	$181,800
Construction overhead	0.05*PEC	$90,900
Contractor Fees	0.1*PEC	$181,800
Start-up	0.02*PEC	$36,400
Performance test	0.01*PEC	$18,200
Contingencies	0.3*PEC	$545,500
Total Capital Cost	**2.08*PEC**	**$3,782,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$189,100
Overhead (60% of labour and maintenance costs)		$127,100
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$44,200
Administrative	2% of TCC	$75,600
Property taxes	1% of TCC	$37,800
Insurance	1% of TCC	$37,800
Operating and Maintenance Cost (O&M)	Sum of Above	**$534,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$616,000
Total Annualized Cost	O&M*capital recovery	**$1,150,000**

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	5376

Table C.10
Brown stock washer emission collection - destruction in recovery boiler - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and Corrected to ($Can 1994)

Total Capital Cost (TCC)	**$4,791,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$2,303,400
Direct installation cost	0.5*PEC	$1,151,700
Engineering	0.1*PEC	$230,300
Construction overhead	0.05*PEC	$115,200
Contractor Fees	0.1*PEC	$230,300
Start-up	0.02*PEC	$46,100
Performance test	0.01*PEC	$23,000
Contingencies	0.3*PEC	$691,000
Total Capital Cost	**2.08*PEC**	**$4,791,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$239,600
Overhead (60% of labour and maintenance costs)		$157,400
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$44,200
Administrative	2% of TCC	$95,800
Property taxes	1% of TCC	$47,900
Insurance	1% of TCC	$47,900
Operating and Maintenance Cost (O&M)	Sum of Above	**$656,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $780,000
Total Annualized Cost	O&M*capital recovery	**$1,436,000**

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 5376

Table C.11
Low Level TRS Collection and Disposal (BSW)
OAQPS Costing Methodology
Capital Cost Reported by Rainy River Forest Products Inc. and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$4,141,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,990,900
Direct installation cost	0.5*PEC	$995,500
Engineering	0.1*PEC	$199,100
Construction overhead	0.05*PEC	$99,500
Contractor Fees	0.1*PEC	$199,100
Start-up	0.02*PEC	$39,800
Performance test	0.01*PEC	$19,900
Contingencies	0.3*PEC	$597,300
Total Capital Cost	**2.08*PEC**	**$4,141,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$12.96/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$207,100
Overhead (60% of labour and maintenance costs)		$137,900
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$104,200
Administrative	2% of TCC	$82,800
Property taxes	1% of TCC	$41,400
Insurance	1% of TCC	$41,400
Operating and Maintenance (O&M)	Sum of above	**$638,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$674,000
Total Annualized Cost		**$1,312,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/day) (U.S.EPA 1979) 5376

Table C.12
Brown stock washer emission collection - destruction in separate incinerator - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$4,035,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,939,900
Direct installation cost	0.5*PEC	$970,000
Engineering	0.1*PEC	$194,000
Construction overhead	0.05*PEC	$97,000
Contractor Fees	0.1*PEC	$194,000
Start-up	0.02*PEC	$38,800
Performance test	0.01*PEC	$19,400
Contingencies	0.3*PEC	$582,000
Total Capital Cost	**2.08*PEC**	**$4,035,000**

Total Annualized Cost	operating days/year	328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$201,800
Overhead (60% of labour and maintenance costs)		$134,700
Utilities (fuel)	$3.30/MBtu	$1,925,300
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$80,700
Property taxes	1% of TCC	$40,400
Insurance	1% of TCC	$40,400
Operating and Maintenance Costs		**$2,550,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $656,000
Total Annualized Cost		**$3,206,000**

Notes

Utilities

fuel (Btu/day)*	1776	(80% of total)
electricity (kWh/day)*	5376	

Table C.13
Brown stock washer emission collection - destruction in separate incinerator - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$6,304,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$3,030,800
Direct installation cost	0.5*PEC	$1,515,400
Engineering	0.1*PEC	$303,100
Construction overhead	0.05*PEC	$151,500
Contractor Fees	0.1*PEC	$303,100
Start-up	0.02*PEC	$60,600
Performance test	0.01*PEC	$30,300
Contingencies	0.3*PEC	$909,200
Total Capital Cost	**2.08*PEC**	**$6,304,000**

Total Annualized Cost	operating days/year	328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$315,200
Overhead (60% of labour and maintenance costs)		$202,700
Utilities (fuel)	$3.30/MBtu	$1,925,300
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$126,100
Property taxes	1% of TCC	$63,000
Insurance	1% of TCC	$63,000
Operating and Maintenance Costs		**$2,822,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$1,025,000
Total Annualized Cost		**$3,847,000**

Notes

Utilities

fuel (Btu/day)*	1776	(80% of total)
electricity (kWh/day)*	5376	

Table C.14
Brown stock washer emission collection - destruction in separate incinerator - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$8,069,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$3,879,300
Direct installation cost	0.5*PEC	$1,939,700
Engineering	0.1*PEC	$387,900
Construction overhead	0.05*PEC	$194,000
Contractor Fees	0.1*PEC	$387,900
Start-up	0.02*PEC	$77,600
Performance test	0.01*PEC	$38,800
Contingencies	0.3*PEC	$1,163,800
Total Capital Cost	**2.08*PEC**	**$8,069,000**

Total Annualized Cost	operating days/year	328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$403,500
Overhead (60% of labour and maintenance costs)		$255,700
Utilities (fuel)	$3.30/MBtu	$1,925,300
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$161,400
Property taxes	1% of TCC	$80,700
Insurance	1% of TCC	$80,700
Operating and Maintenance Costs		**$3,034,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$1,312,000
Total Annualized Cost		**$4,346,000**

Notes

Utilities

fuel (Btu/day)*	1776	(80% of total)
electricity (kWh/day)*	5376	

Table C.15
Separate Incinerator
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$5,000,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$2,403,800
Direct installation cost	0.5*PEC	$1,201,900
Engineering	0.1*PEC	$240,400
Construction overhead	0.05*PEC	$120,200
Contractor Fees	0.1*PEC	$240,400
Start-up	0.02*PEC	$48,100
Performance test	0.01*PEC	$24,000
Contingencies	0.3*PEC	$721,100
Total Capital Cost	**2.08*PEC**	**$5,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$250,000
Overhead (60% of labour and maintenance costs)		$163,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$55,800
Administrative	2% of TCC	$100,000
Property taxes	1% of TCC	$50,000
Insurance	1% of TCC	$50,000
Caustic make-up for scrubber*		$750,000
Operating and Maintenance (O&M)	Sum of Above	**$1,442,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$814,000
Total Annualized Cost		**$3,698,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979) 0
electricity(kWh)/day (U.S.EPA 1979) 2880

* Blackwell 1994

Table C.16
Steam stripping of pulping wastewater followed by combustion (existing)
- integrated with evaporator set - 500 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,753,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$842,800
Direct installation cost	0.5*PEC	$421,400
Engineering	0.1*PEC	$84,300
Construction overhead	0.05*PEC	$42,100
Contractor Fees	0.1*PEC	$84,300
Start-up	0.02*PEC	$16,900
Performance test	0.01*PEC	$8,400
Contingencies	0.3*PEC	$252,800
Total Capital Cost	**2.08*PEC**	**$1,753,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	*	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Costs	5% of TCC	$87,700
Overhead (60% of labour and maintenance costs)		$52,600
Utilities (steam)	$4.02/Mg*	$174,200
Utilities (electricity)	$0.059/kwh	$51,900
Administrative	2% of TCC	$35,100
Property taxes	1% of TCC	$17,500
Insurance	1% of TCC	$17,500
Operating and Maintenance Cost (O&M)		**$437,000**
Capital recovery	capital recovery factor * TCC	
10 year @ 10%	0.16275*TCC	$285,300
Recovery Credit		($111,214)
Total Annualized Cost		**$611,000**

* U.S.EPA 1993a

Notes:

Utilities	
electricity (kWh/y) - (U.S.EPA 1993a)	879211
steam (Mg/year)*	43343.85
Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$450,687
purchased equipment cost stainless steel	$585,893
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$842,800

It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.17
Steam stripping of pulping wastewater followed by combustion (existing)
- integrated with evaporator set - 1000 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$3,788,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$1,821,200
Direct installation cost	0.5*PEC	$910,600
Engineering	0.1*PEC	$182,100
Construction overhead	0.05*PEC	$91,100
Contractor Fees	0.1*PEC	$182,100
Start-up	0.02*PEC	$36,400
Performance test	0.01*PEC	$18,200
Contingencies	0.3*PEC	$546,400
Total Capital Cost	**2.08*PEC**	**$3,788,100**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	*	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Costs	5% of TCC	$189,400
Overhead (60% of labour and maintenance costs)		$113,600
Utilities (steam)	$4.02/Mg*	$250,000
Utilities (electricity)	$0.059/kwh	$51,900
Administrative	2% of TCC	$75,800
Property taxes	1% of TCC	$37,900
Insurance	1% of TCC	$37,900
Operating and Maintenance Cost (O&M)		**$757,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $616,500
Recovery Credit		($111,214)
Total Annualized Cost		**$1,262,000**

* U.S.EPA 1993a

Notes:

Utilities	
electricity (kWh/y) - (U.S.EPA 1993a)	879211
steam (Mg/year)*	62189.00
Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$973,887
purchased equipment cost stainless steel	$1,266,053
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$1,821,200

It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.18
Steam stripping of pulping wastewater followed by combustion (existing)
- integrated with evaporator set - 1500 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	$4,979,000

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$2,393,800
Direct installation cost	0.5*PEC	$1,196,900
Engineering	0.1*PEC	$239,400
Construction overhead	0.05*PEC	$119,700
Contractor Fees	0.1*PEC	$239,400
Start-up	0.02*PEC	$47,900
Performance test	0.01*PEC	$23,900
Contingencies	0.3*PEC	$718,100
Total Capital Cost	**2.08*PEC**	**$4,979,100**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	*	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Costs	5% of TCC	$249,000
Overhead (60% of labour and maintenance costs)		$149,400
Utilities (steam)	$4.02/Mg*	$303,000
Utilities (electricity)	$0.059/kwh	$51,900
Administrative	2% of TCC	$99,600
Property taxes	1% of TCC	$49,800
Insurance	1% of TCC	$49,800
Operating and Maintenance Cost (O&M)		**$953,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $810,300
Recovery Credit		($111,214)
Total Annualized Cost		**$1,652,000**

* U.S.EPA 1993a

Notes:

Utilities	
electricity (kWh/y) - (U.S.EPA 1993a)	879211
steam (Mg/year)*	75380.61
Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$1,280,085
purchased equipment cost stainless steel	$1,664,110
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$2,393,800

It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.19
Steam stripping of pulping wastewater followed by combustion (existing)
- Not integrated with evaporator set - 500 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$3,997,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$1,921,600
Direct installation cost	0.5*PEC	$960,800
Engineering	0.1*PEC	$192,200
Construction overhead	0.05*PEC	$96,100
Contractor Fees	0.1*PEC	$192,200
Start-up	0.02*PEC	$38,400
Performance test	0.01*PEC	$19,200
Contingencies	0.3*PEC	$576,500
Total Capital Cost	**2.08*PEC**	**$3,997,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	*	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Costs	5% of TCC	$199,900
Overhead (60% of labour and maintenance costs)		$119,900
Utilities (steam)	$4.02/Mg*	$2,021,200
Utilities (electricity)	$0.059/kwh	$51,900
Administrative	2% of TCC	$79,900
Property taxes	1% of TCC	$40,000
Insurance	1% of TCC	$40,000
Operating and Maintenance Cost (O&M)		**$2,553,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$650,500
Recovery Credit		($111,214)
Total Annualized Cost		**$3,092,000**

* U.S.EPA 1993a

Notes:

Utilities	
electricity (kWh/y) - (U.S.EPA 1993a)	879211
steam (Mg/year)*	502789.06
Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$1,027,576
purchased equipment cost stainless steel	$1,335,848
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$1,921,600

It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.20
Steam stripping of pulping wastewater followed by combustion (existing)
- Not integrated with evaporator set - 1000 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$8,636,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$4,151,900
Direct installation cost	0.5*PEC	$2,076,000
Engineering	0.1*PEC	$415,200
Construction overhead	0.05*PEC	$207,600
Contractor Fees	0.1*PEC	$415,200
Start-up	0.02*PEC	$83,000
Performance test	0.01*PEC	$41,500
Contingencies	0.3*PEC	$1,245,600
Total Capital Cost	**2.08*PEC**	**$8,636,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	*	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Costs	5% of TCC	$431,800
Overhead (60% of labour and maintenance costs)		$259,100
Utilities (steam)	$4.02/Mg*	$2,900,000
Utilities (electricity)	$0.059/kwh	$51,900
Administrative	2% of TCC	$172,700
Property taxes	1% of TCC	$86,400
Insurance	1% of TCC	$86,400
Operating and Maintenance Cost (O&M)		**$3,988,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$1,405,500
Recovery Credit		($111,214)
Total Annualized Cost		**$5,282,000**

* U.S.EPA 1993a

Notes:

Utilities	
electricity (kWh/y) - (U.S.EPA 1993a)	879211
steam (Mg/year)*	721393.00
Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$2,220,229
purchased equipment cost stainless steel	$2,886,297
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$4,151,900

It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.21
Steam stripping of pulping wastewater followed by combustion (existing)
- Not integrated with evaporator set - 1500 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1993a and corrected to ($Can 1994)

Total Capital Cost (TCC)	$11,350,000

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$5,456,700
Direct installation cost	0.5*PEC	$2,728,400
Engineering	0.1*PEC	$545,700
Construction overhead	0.05*PEC	$272,800
Contractor Fees	0.1*PEC	$545,700
Start-up	0.02*PEC	$109,100
Performance test	0.01*PEC	$54,600
Contingencies	0.3*PEC	$1,637,000
Total Capital Cost	**2.08*PEC**	**$11,350,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	*	$0
Supervisory Labour	15% of operating labour	$0
Maintenance Costs	5% of TCC	$567,500
Overhead (60% of labour and maintenance costs)		$340,500
Utilities (steam)	$4.02/Mg*	$3,515,200
Utilities (electricity)	$0.059/kwh	$51,900
Administrative	2% of TCC	$227,000
Property taxes	1% of TCC	$113,500
Insurance	1% of TCC	$113,500
Operating and Maintenance Cost (O&M)		**$4,929,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $1,847,200
Recovery Credit		($111,214)
Total Annualized Cost		**$6,665,000**

* U.S.EPA 1993a

Notes:

Utilities	
electricity (kWh/y) - (U.S.EPA 1993a)	879211
steam (Mg/year)*	874415.76
Btu-kWh conversion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$2,917,970
purchased equipment cost stainless steel	$3,793,361
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$5,456,700

It was assumed that an increase in operating labour due to the duct work is insignificant (U.S.EPA 1993a)

Table C.22
Steam Stripping (1000 TPD)
OAQPS Methodology ($Can 1994)
Capital Cost reported by Blackwell 1994

Total Capital Cost (TCC)	**$5,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$2,403,800
Direct installation cost	0.5*PEC	$1,201,900
Engineering	0.1*PEC	$240,400
Construction overhead	0.05*PEC	$120,200
Contractor Fees	0.1*PEC	$240,400
Start-up	0.02*PEC	$48,100
Performance test	0.01*PEC	$24,000
Contingencies	0.3*PEC	$721,100
Total Capital Cost	**2.08*PEC**	**$5,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,710
Supervisory Labour	15% of operating labour	$2,957
Maintenance Cost	5% of TCC	$250,000
Overhead (60% of labour and maintenance costs)		$163,600
Utilities (steam)	$4.02/Mg*	$2,900,000
Utilities (electricity)	$0.059/kwh	$51,900
Administrative	2% of TCC	$100,000
Property taxes	1% of TCC	$50,000
Insurance	1% of TCC	$50,000
Operating and Maintenance Cost (O&M)		**$3,588,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $813,800
Recovery Credit*		($111,214)
Total Annualized Cost		**$4,291,000**

Utilities

fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979)	0
electricity (kWh/y) - (U.S.EPA 1993a)	879210.5393
steam (Mg/year)*	721393.00

* U.S.EPA 1993a

Table C.23
Contaminated Condensate Steam Stripper (1000 TPD)
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Rainy River Forest Products Inc. and converted to ($Can 1994)

Total Capital Cost (TCC)	**$5,383,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$2,588,000
Direct installation cost	0.5*PEC	$1,294,000
Engineering	0.1*PEC	$258,800
Construction overhead	0.05*PEC	$129,400
Contractor Fees	0.1*PEC	$258,800
Start-up	0.02*PEC	$51,800
Performance test	0.01*PEC	$25,900
Contingencies	0.3*PEC	$776,400
Total Capital Cost	**2.08*PEC**	**$5,383,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,710
Supervisory Labour	15% of operating labour	$2,957
Maintenance Cost	5% of TCC	$269,200
Overhead (60% of labour and maintenance costs)		$175,100
Utilities (steam)	$4.02/Mg*	$2,900,000
Utilities (electricity)	$0.059/kwh	$51,900
Administrative	2% of TCC	$107,700
Property taxes	1% of TCC	$53,800
Insurance	1% of TCC	$53,800
Operating and Maintenance Cost (O&M)		**$3,634,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $876,100
Recovery Credit*		($111,214)
Total Annualized Cost		**$4,399,000**

Utilities

fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979)	0
electricity (kWh/y) - (U.S.EPA 1993a)	879210.5393
steam (Mg/year)*	721393.00

* U.S.EPA 1993a

Table C.24
Retrofit Cost for Recovery Furnace - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost reported by U.S.EPA 1979 and converted to ($Can 1994)

Total Capital Cost (TCC)	**$33,790,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$16,245,200
Direct installation cost	0.5*PEC	$8,122,600
Engineering	0.1*PEC	$1,624,500
Construction overhead	0.05*PEC	$812,300
Contractor Fees	0.1*PEC	$1,624,500
Start-up	0.02*PEC	$324,900
Performance test	0.01*PEC	$162,500
Contingencies	0.3*PEC	$4,873,600
Total Capital Cost	**2.08*PEC**	**$33,790,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$1,181,600
Utilities (electricity)	$0.057/kWh	$0
Administrative	2% of TCC	$675,800
Property taxes	1% of TCC	$337,900
Insurance	1% of TCC	$337,900
Operating and Maintenance Cost (O&M)		**$2,570,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$5,499,000
Total Annualized Cost		**$8,069,000**

*Maintenance costs incurred for replacement would be offset by maintenance charges foregone in scrapping the old equipment (U.S.EPA 1979)

Notes

Utilities

fuel (Btu/day)*	1090
electricity (kWh/day)*	0

Table C.25
Retrofit Cost for Recovery Furnace - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost reported by U.S.EPA 1979 and converted to ($Can 1994)

Total Capital Cost (TCC)	**$58,753,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$28,246,600
Direct installation cost	0.5*PEC	$14,123,300
Engineering	0.1*PEC	$2,824,700
Construction overhead	0.05*PEC	$1,412,300
Contractor Fees	0.1*PEC	$2,824,700
Start-up	0.02*PEC	$564,900
Performance test	0.01*PEC	$282,500
Contingencies	0.3*PEC	$8,474,000
Total Capital Cost	**2.08*PEC**	**$58,753,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$1,181,600
Utilities (electricity)	$0.057/kWh	$0
Administrative	2% of TCC	$1,175,100
Property taxes	1% of TCC	$587,500
Insurance	1% of TCC	$587,500
Operating and Maintenance Cost (O&M)		**$3,568,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $9,562,000
Total Annualized Cost		**$13,130,000**

*Maintenance costs incurred for replacement would be offset by maintenance charges foregone in scrapping the old equipment (U.S.EPA 1979)

Notes

Utilities

fuel (Btu/day)*	1090
electricity (kWh/day)*	0

Table C.26
Retrofit Cost for Recovery Furnace - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost reported by U.S.EPA 1979 and converted to ($Can 1994)

Total Capital Cost (TCC)	**$81,196,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$39,036,500
Direct installation cost	0.5*PEC	$19,518,300
Engineering	0.1*PEC	$3,903,700
Construction overhead	0.05*PEC	$1,951,800
Contractor Fees	0.1*PEC	$3,903,700
Start-up	0.02*PEC	$780,700
Performance test	0.01*PEC	$390,400
Contingencies	0.3*PEC	$11,711,000
Total Capital Cost	**2.08*PEC**	**$81,196,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$1,181,600
Utilities (electricity)	$0.057/kWh	$0
Administrative	2% of TCC	$1,623,900
Property taxes	1% of TCC	$812,000
Insurance	1% of TCC	$812,000
Operating and Maintenance Cost (O&M)		**$4,466,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $13,215,000
Total Annualized Cost		**$17,681,000**

*Maintenance costs incurred for replacement would be offset by maintenance charges foregone in scrapping the old equipment (U.S.EPA 1979)

Notes

Utilities

fuel (Btu/day)*	1090
electricity (kWh/day)*	0

Table C.27
Recovery Boiler Low Odour Conversion - 1000 TPD
OAQPS Costing Methodology ($CAN1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$35,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$16,827,000
Direct installation cost	0.5*PEC	$8,414,000
Engineering	0.1*PEC	$1,683,000
Construction overhead	0.05*PEC	$841,000
Contractor Fees	0.1*PEC	$1,683,000
Start-up	0.02*PEC	$337,000
Performance test	0.01*PEC	$168,000
Contingencies	0.3*PEC	$5,048,000
Total Capital Cost	**2.08*PEC**	**$35,001,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$20,000
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$1,750,000
Overhead (60% of labour and maintenance costs)		$1,064,000
Utilities (fuel)	$3.30/1000ft^3	$1,182,000
Utilities (electricity)	$0.059/kwh	$0
Administrative	2% of TCC	$700,000
Property taxes	1% of TCC	$350,000
Insurance	1% of TCC	$350,000
Operating and Maintenance Cost (O&M)		**$5,419,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $5,696,000
Total Annualized Cost		**$11,115,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day 1090
electricity(kWh)/day

Table C.28
Recovery Boiler Low Odour Conversion
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by H.A. Simons 1994

Total Capital Cost (TCC)	**$35,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$16,826,900
Direct installation cost	0.5*PEC	$8,413,500
Engineering	0.1*PEC	$1,682,700
Construction overhead	0.05*PEC	$841,300
Contractor Fees	0.1*PEC	$1,682,700
Start-up	0.02*PEC	$336,500
Performance test	0.01*PEC	$168,300
Contingencies	0.3*PEC	$5,048,100
Total Capital Cost	**2.08*PEC**	**$35,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$1,750,000
Overhead (60% of labour and maintenance costs)		$1,063,600
Utilities (fuel)	$3.30/1000ft^3	$1,181,615
Utilities (electricity)	$0.059/kwh	$0
Administrative	2% of TCC	$700,000
Property taxes	1% of TCC	$350,000
Insurance	1% of TCC	$350,000
Operating and Maintenance Cost (O&M)		**$5,418,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $5,696,000
Total Annualized Cost		**$11,114,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day 1090 (U.S.EPA 1979)
electricity(kWh)/day

Table C.29
Retrofit cost for second stage black liquor oxidation - 500 TPD
OAQPS Costing Methodology ($Can1994)
Capital Costs Reported by U.S.EPA 1979 and converted to ($Can 1994)

Total Capital Cost (TCC)	**$1,513,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$727,400
Direct installation cost	0.5*PEC	$363,700
Engineering	0.1*PEC	$72,700
Construction overhead	0.05*PEC	$36,400
Contractor Fees	0.1*PEC	$72,700
Start-up	0.02*PEC	$14,500
Performance test	0.01*PEC	$7,300
Contingencies	0.3*PEC	$218,200
Total Capital Cost	**2.08*PEC**	**$1,513,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour	5% of TCC	$75,700
Overhead (60% of labour and maintenance costs)		$59,000
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$279,100
Administrative	2% of TCC	$30,300
Property taxes	1% of TCC	$15,100
Insurance	1% of TCC	$15,100
Operating and Maintenance Cost (O&M)		**$399,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$246,000
Total Annualized Cost		**$645,000**

Notes

Utilities
fuel (Btu/day) 0
electricity (kWh/day) 14400
*Maintenance Costs for black liquor oxidation systems are estimated at 4% of capital cost (U.S.EPA 1979)

Table C.30
Retrofit cost for second stage black liquor oxidation - 1000 TPD
OAQPS Costing Methodology ($Can1994)
Capital Costs Reported by U.S.EPA 1979 and converted to ($Can 1994)

Total Capital Cost (TCC)	**$2,522,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$1,212,500
Direct installation cost	0.5*PEC	$606,300
Engineering	0.1*PEC	$121,300
Construction overhead	0.05*PEC	$60,600
Contractor Fees	0.1*PEC	$121,300
Start-up	0.02*PEC	$24,300
Performance test	0.01*PEC	$12,100
Contingencies	0.3*PEC	$363,800
Total Capital Cost	**2.08*PEC**	**$2,522,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour	5% of TCC	$126,100
Overhead (60% of labour and maintenance costs)		$89,300
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$279,100
Administrative	2% of TCC	$50,400
Property taxes	1% of TCC	$25,200
Insurance	1% of TCC	$25,200
Operating and Maintenance Cost (O&M)		**$469,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$410,000
Total Annualized Cost		**$879,000**

Notes

Utilities
fuel (Btu/day) 0
electricity (kWh/day) 14400
*Maintenance Costs for black liquor oxidation systems are estimated at 4% of capital cost (U.S.EPA 1979)

Table C.31
Retrofit cost for second stage black liquor oxidation - 1500 TPD
OAQPS Costing Methodology ($Can1994)
Capital Costs Reported by U.S.EPA 1979 and converted to ($Can 1994)

Total Capital Cost (TCC)	**$3,782,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	1*PEC	$1,818,300
Direct installation cost	0.5*PEC	$909,200
Engineering	0.1*PEC	$181,800
Construction overhead	0.05*PEC	$90,900
Contractor Fees	0.1*PEC	$181,800
Start-up	0.02*PEC	$36,400
Performance test	0.01*PEC	$18,200
Contingencies	0.3*PEC	$545,500
Total Capital Cost	**2.08*PEC**	**$3,782,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour	5% of TCC	$189,100
Overhead (60% of labour and maintenance costs)		$127,100
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$279,100
Administrative	2% of TCC	$75,600
Property taxes	1% of TCC	$37,800
Insurance	1% of TCC	$37,800
Operating and Maintenance Cost (O&M)		**$557,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$616,000
Total Annualized Cost		**$1,173,000**

Notes

Utilities
fuel (Btu/day) 0
electricity (kWh/day) 14400
*Maintenance Costs for black liquor oxidation systems are estimated at 4% of capital cost (U.S.EPA 1979)

Table C.32
Black liquor oxidation system
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$2,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$961,500
Direct installation cost	0.5*PEC	$480,800
Engineering	0.1*PEC	$96,200
Construction overhead	0.05*PEC	$48,100
Contractor Fees	0.1*PEC	$96,200
Start-up	0.02*PEC	$19,200
Performance test	0.01*PEC	$9,600
Contingencies	0.3*PEC	$288,500
Total Capital Cost	**2.08*PEC**	**$2,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$100,000
Overhead (60% of labour and maintenance costs)		$73,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$279,100
Administrative	2% of TCC	$40,000
Property taxes	1% of TCC	$20,000
Insurance	1% of TCC	$20,000
Operating and Maintenance Cost (O&M)		**$555,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $326,000
Total Annualized Cost		**$881,000**

Utilities

fuel (1000 ft^3 = 1 MBtu) (MBtu)/day	0	(U.S.EPA 1979)
electricity(kWh)/day	14400	(U.S.EPA 1979)

Table C.33
Black liquor oxidation vents - destruction in recovery boiler - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$555,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$266,800
Direct installation cost	0.5*PEC	$133,400
Engineering	0.1*PEC	$26,700
Construction overhead	0.05*PEC	$13,300
Contractor Fees	0.1*PEC	$26,700
Start-up	0.02*PEC	$5,300
Performance test	0.01*PEC	$2,700
Contingencies	0.3*PEC	$80,000
Total Capital Cost	**2.08*PEC**	**$555,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$27,800
Overhead (60% of labour and maintenance costs)		$30,300
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$11,100
Property taxes	1% of TCC	$5,550
Insurance	1% of TCC	$5,550
Operating and Maintenance (O&M)		**$207,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $90,000
Total Annualized Cost		**$297,000**

* U.S.EPA 1979

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 5376

Table C.34
Black liquor oxidation vents - destruction in recovery boiler - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$832,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$400,000
Direct installation cost	0.5*PEC	$200,000
Engineering	0.1*PEC	$40,000
Construction overhead	0.05*PEC	$20,000
Contractor Fees	0.1*PEC	$40,000
Start-up	0.02*PEC	$8,000
Performance test	0.01*PEC	$4,000
Contingencies	0.3*PEC	$120,000
Total Capital Cost	**2.08*PEC**	**$832,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$41,600
Overhead (60% of labour and maintenance costs)		$38,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$16,640
Property taxes	1% of TCC	$8,320
Insurance	1% of TCC	$8,320
Operating and Maintenance (O&M)		**$240,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $135,000
Total Annualized Cost		**$375,000**

* U.S.EPA 1979

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	5376

Table C.35
Black liquor oxidation vents - destruction in recovery boiler - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,089,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$523,600
Direct installation cost	0.5*PEC	$261,800
Engineering	0.1*PEC	$52,400
Construction overhead	0.05*PEC	$26,200
Contractor Fees	0.1*PEC	$52,400
Start-up	0.02*PEC	$10,500
Performance test	0.01*PEC	$5,200
Contingencies	0.3*PEC	$157,100
Total Capital Cost	**2.08*PEC**	**$1,089,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$54,500
Overhead (60% of labour and maintenance costs)		$46,300
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$21,780
Property taxes	1% of TCC	$10,890
Insurance	1% of TCC	$10,890
Operating and Maintenance (O&M)		**$271,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $177,000
Total Annualized Cost		**$448,000**

* U.S.EPA 1979

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	5376

Table C.36
Black liquor oxidation vents - destruction in separtate incinerator - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,009,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$485,100
Direct installation cost	0.5*PEC	$242,600
Engineering	0.1*PEC	$48,500
Construction overhead	0.05*PEC	$24,300
Contractor Fees	0.1*PEC	$48,500
Start-up	0.02*PEC	$9,700
Performance test	0.01*PEC	$4,900
Contingencies	0.3*PEC	$145,500
Total Capital Cost	**2.08*PEC**	**$1,009,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$50,500
Overhead (60% of labour and maintenance costs)		$43,900
Utilities (fuel)	$3.30/MBtu	$498,700
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$20,180
Property taxes	1% of TCC	$10,090
Insurance	1% of TCC	$10,090
Operating and Maintenance (O&M)		**$760,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $164,000
Total Annualized Cost		**$924,000**

Notes

Utilities
fuel (Btu/day)* 460 (20% of BSW)
electricity (kWh/day)* 5376
* U.S.EPA 1979

Table C.37
Black liquor oxidation vents - destruction in separtate incinerator - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,412,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$678,800
Direct installation cost	0.5*PEC	$339,400
Engineering	0.1*PEC	$67,900
Construction overhead	0.05*PEC	$33,900
Contractor Fees	0.1*PEC	$67,900
Start-up	0.02*PEC	$13,600
Performance test	0.01*PEC	$6,800
Contingencies	0.3*PEC	$203,600
Total Capital Cost	**2.08*PEC**	**$1,412,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$70,600
Overhead (60% of labour and maintenance costs)		$56,000
Utilities (fuel)	$3.30/MBtu	$498,700
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$28,240
Property taxes	1% of TCC	$14,120
Insurance	1% of TCC	$14,120
Operating and Maintenance (O&M)		**$809,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $230,000
Total Annualized Cost		**$1,039,000**

Notes

Utilities
fuel (Btu/day)* 460 (20% of BSW)
electricity (kWh/day)* 5376
* U.S.EPA 1979

Table C.38
Black liquor oxidation vents - destruction in separtate incinerator - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,765,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$848,600
Direct installation cost	0.5*PEC	$424,300
Engineering	0.1*PEC	$84,900
Construction overhead	0.05*PEC	$42,400
Contractor Fees	0.1*PEC	$84,900
Start-up	0.02*PEC	$17,000
Performance test	0.01*PEC	$8,500
Contingencies	0.3*PEC	$254,600
Total Capital Cost	**2.08*PEC**	**$1,765,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$88,300
Overhead (60% of labour and maintenance costs)		$66,600
Utilities (fuel)	$3.30/MBtu	$498,700
Utilities (electricity)	$0.059/kWh	$104,200
Administrative	2% of TCC	$35,300
Property taxes	1% of TCC	$17,650
Insurance	1% of TCC	$17,650
Operating and Maintenance (O&M)		**$851,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$287,000
Total Annualized Cost		**$1,138,000**

Notes

Utilities

fuel (Btu/day)*	460	(20% of BSW)
electricity (kWh/day)*	5376	

* U.S.EPA 1979

Table C.39
Black liquor oxidation vents - molecular oxygen - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$2,723,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,309,100
Direct installation cost	0.5*PEC	$654,600
Engineering	0.1*PEC	$130,900
Construction overhead	0.05*PEC	$65,500
Contractor Fees	0.1*PEC	$130,900
Start-up	0.02*PEC	$26,200
Performance test	0.01*PEC	$13,100
Contingencies	0.3*PEC	$392,700
Total Capital Cost	**2.08*PEC**	**$2,723,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$136,200
Overhead (60% of labour and maintenance costs)		$95,300
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$387,600
Administrative	2% of TCC	$54,460
Property taxes	1% of TCC	$27,230
Insurance	1% of TCC	$27,230
Operating and Maintenance Cost (O&M)		**$751,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$443,000
Total Annualized Cost		**$1,194,000**

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 20000
* U.S.EPA 1979

Table C.40
Black liquor oxidation vents - molecular oxygen - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$4,135,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,988,000
Direct installation cost	0.5*PEC	$994,000
Engineering	0.1*PEC	$198,800
Construction overhead	0.05*PEC	$99,400
Contractor Fees	0.1*PEC	$198,800
Start-up	0.02*PEC	$39,800
Performance test	0.01*PEC	$19,900
Contingencies	0.3*PEC	$596,400
Total Capital Cost	**2.08*PEC**	**$4,135,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$206,800
Overhead (60% of labour and maintenance costs)		$137,700
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$387,600
Administrative	2% of TCC	$82,700
Property taxes	1% of TCC	$41,350
Insurance	1% of TCC	$41,350
Operating and Maintenance Cost (O&M)		**$920,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $673,000
Total Annualized Cost		**$1,593,000**

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 20000
* U.S.EPA 1979

Table C.41
Black liquor oxidation vents - molecular oxygen - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$5,295,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$2,545,700
Direct installation cost	0.5*PEC	$1,272,900
Engineering	0.1*PEC	$254,600
Construction overhead	0.05*PEC	$127,300
Contractor Fees	0.1*PEC	$254,600
Start-up	0.02*PEC	$50,900
Performance test	0.01*PEC	$25,500
Contingencies	0.3*PEC	$763,700
Total Capital Cost	**2.08*PEC**	**$5,295,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$264,800
Overhead (60% of labour and maintenance costs)		$172,500
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$387,600
Administrative	2% of TCC	$105,900
Property taxes	1% of TCC	$52,950
Insurance	1% of TCC	$52,950
Operating and Maintenance Cost (O&M)		**$1,059,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $862,000
Total Annualized Cost		**$1,921,000**

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 20000
* U.S.EPA 1979

Table C.42
Black liquor oxidation system - molecular oxygen
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$1,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$480,800
Direct installation cost	0.5*PEC	$240,400
Engineering	0.1*PEC	$48,100
Construction overhead	0.05*PEC	$24,000
Contractor Fees	0.1*PEC	$48,100
Start-up	0.02*PEC	$9,600
Performance test	0.01*PEC	$4,800
Contingencies	0.3*PEC	$144,200
Total Capital Cost	**2.08*PEC**	**$1,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Costs	5% of TCC	$50,000
Overhead (60% of labour and maintenance costs)		$43,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$387,600
Administrative	2% of TCC	$20,000
Property taxes	1% of TCC	$10,000
Insurance	1% of TCC	$10,000
Operating and Maintenance Cost (O&M)		**$544,000**
Capital recovery	capital recovery factor * TCC	
10 year @ 10%	0.16275*TCC	$163,000
Purchase of oxygen		$200,000
Total Annualized Cost		**$907,000**

Utilities

fuel (1000 ft^3 = 1 MBtu) (MBtu)/day	0	(U.S.EPA 1979)
electricity(kWh)/day	20000	(U.S.EPA 1979)

Table C.43
Batch digesters - low retrofit penalty - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Costs Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,009,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$485,100
Direct installation cost	0.5*PEC	$242,600
Engineering	0.1*PEC	$48,500
Construction overhead	0.05*PEC	$24,300
Contractor Fees	0.1*PEC	$48,500
Start-up	0.02*PEC	$9,700
Performance test	0.01*PEC	$4,900
Contingencies	0.3*PEC	$145,500
Total Capital Cost	**2.08*PEC**	**$1,009,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$50,500
Overhead (60% of labour and maintenance costs)		$43,900
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$20,200
Property taxes	1% of TCC	$10,100
Insurance	1% of TCC	$10,100
Operating and Maintenance Cost (O&M)		**$213,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $164,000
Total Annualized Cost		**$377,000**

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 2880
* U.S.EPA 1979

Table C.44
Batch digesters - low retrofit penalty - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Costs Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	$2,269,000

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,090,900
Direct installation cost	0.5*PEC	$545,500
Engineering	0.1*PEC	$109,100
Construction overhead	0.05*PEC	$54,500
Contractor Fees	0.1*PEC	$109,100
Start-up	0.02*PEC	$21,800
Performance test	0.01*PEC	$10,900
Contingencies	0.3*PEC	$327,300
Total Capital Cost	**2.08*PEC**	**$2,269,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Overhead (60% of labour and maintenance costs)		$25,400
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$45,400
Property taxes	1% of TCC	$22,700
Insurance	1% of TCC	$22,700
Operating and Maintenance Cost (O&M)		**$214,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $369,000
Total Annualized Cost		**$583,000**

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 2880
* U.S.EPA 1979

Table C.45
Batch digesters - low retrofit penalty - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Costs Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$4,035,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,939,900
Direct installation cost	0.5*PEC	$970,000
Engineering	0.1*PEC	$194,000
Construction overhead	0.05*PEC	$97,000
Contractor Fees	0.1*PEC	$194,000
Start-up	0.02*PEC	$38,800
Performance test	0.01*PEC	$19,400
Contingencies	0.3*PEC	$582,000
Total Capital Cost	**2.08*PEC**	**$4,035,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Overhead (60% of labour and maintenance costs)		$25,400
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$80,700
Property taxes	1% of TCC	$40,400
Insurance	1% of TCC	$40,400
Operating and Maintenance Cost (O&M)		**$285,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$657,000
Total Annualized Cost		**$942,000**

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	2880

* U.S.EPA 1979

Table C.46
Batch digesters - high retrofit penalty - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Costs Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$2,269,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,090,900
Direct installation cost	0.5*PEC	$545,500
Engineering	0.1*PEC	$109,100
Construction overhead	0.05*PEC	$54,500
Contractor Fees	0.1*PEC	$109,100
Start-up	0.02*PEC	$21,800
Performance test	0.01*PEC	$10,900
Contingencies	0.3*PEC	$327,300
Total Capital Cost	**2.08*PEC**	**$2,269,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$113,500
Overhead (60% of labour and maintenance costs)		$81,700
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$45,400
Property taxes	1% of TCC	$22,700
Insurance	1% of TCC	$22,700
Operating and Maintenance Cost (O&M)		**$365,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $369,000
Total Annualized Cost		**$734,000**

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 2880
* U.S.EPA 1979

Table C.47
Batch digesters - low retrofit penalty - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Costs Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$5,043,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$2,424,500
Direct installation cost	0.5*PEC	$1,212,300
Engineering	0.1*PEC	$242,500
Construction overhead	0.05*PEC	$121,200
Contractor Fees	0.1*PEC	$242,500
Start-up	0.02*PEC	$48,500
Performance test	0.01*PEC	$24,200
Contingencies	0.3*PEC	$727,400
Total Capital Cost	**2.08*PEC**	**$5,043,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Overhead (60% of labour and maintenance costs)		$25,400
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$100,900
Property taxes	1% of TCC	$50,400
Insurance	1% of TCC	$50,400
Operating and Maintenance Cost (O&M)		**$325,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $821,000
Total Annualized Cost		**$1,146,000**

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 2880
*. U.S.EPA 1979

Table C.48
Batch digesters - low retrofit penalty - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Costs Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$8,826,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$4,243,300
Direct installation cost	0.5*PEC	$2,121,700
Engineering	0.1*PEC	$424,300
Construction overhead	0.05*PEC	$212,200
Contractor Fees	0.1*PEC	$424,300
Start-up	0.02*PEC	$84,900
Performance test	0.01*PEC	$42,400
Contingencies	0.3*PEC	$1,273,000
Total Capital Cost	**2.08*PEC**	**$8,826,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Overhead (60% of labour and maintenance costs)		$25,400
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$176,500
Property taxes	1% of TCC	$88,300
Insurance	1% of TCC	$88,300
Operating and Maintenance Cost (O&M)		**$477,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $1,436,000
Total Annualized Cost		**$1,913,000**

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	2880

* U.S.EPA 1979

Table C.49
Incineration of digester and evaporator gases in lime kiln
OAQPS Costing Methodology ($Can 1994)
Capital Costs Reported by Blackwell 1994

Total Capital Cost (TCC)	**$2,000,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$961,500
Direct installation cost	0.5*PEC	$480,800
Engineering	0.1*PEC	$96,200
Construction overhead	0.05*PEC	$48,100
Contractor Fees	0.1*PEC	$96,200
Start-up	0.02*PEC	$19,200
Performance test	0.01*PEC	$9,600
Contingencies	0.3*PEC	$288,500
Total Capital Cost	**2.08*PEC**	**$2,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$100,000
Overhead (60% of labour and maintenance costs)		$73,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$40,000
Property taxes	1% of TCC	$20,000
Insurance	1% of TCC	$20,000
Operating and Maintenance Cost (O&M)		**$332,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$326,000
Total Annualized Cost		**$658,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day 0
electricity(kWh)/day (U.S.EPA 1979) 2880

Table C.50
Non-condensible gas disposal system
OAQPS Costing Methodology ($Can 1994)
Capital Costs Reported by Rainy River Forest Products Inc. and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$4,659,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$2,239,900
Direct installation cost	0.5*PEC	$1,120,000
Engineering	0.1*PEC	$224,000
Construction overhead	0.05*PEC	$112,000
Contractor Fees	0.1*PEC	$224,000
Start-up	0.02*PEC	$44,800
Performance test	0.01*PEC	$22,400
Contingencies	0.3*PEC	$672,000
Total Capital Cost	**2.08*PEC**	**$4,659,000**

Total Annual Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$233,000
Overhead (60% of labour and maintenance costs)		$153,400
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$93,200
Property taxes	1% of TCC	$46,600
Insurance	1% of TCC	$46,600
Operating and Maintenance Cost (O&M)		**$651,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $758,000
Total Annualized Cost		**$1,409,000**

Utilities

fuel (1000 ft^3 = 1 MBtu) (MBtu)/day	0
electricity(kWh)/day (U.S.EPA 1979)	2880

Table C.51
Collection of Continuous Digester Vent Gases and Incineration
OAQPS Costing Methodology ($Can 1994) 500 TPD Pulp Mill
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$756,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$363,500
Direct installation cost	0.5*PEC	$181,800
Engineering	0.1*PEC	$36,400
Construction overhead	0.05*PEC	$18,200
Contractor Fees	0.1*PEC	$36,400
Start-up	0.02*PEC	$7,300
Performance test	0.01*PEC	$3,600
Contingencies	0.3*PEC	$109,100
Total Capital Cost	**2.08*PEC**	**$756,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$37,800
Overhead (60% of labour and maintenance costs)		$36,300
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$15,100
Property taxes	1% of TCC	$7,600
Insurance	1% of TCC	$7,600
Operating and Maintenance Cost (O&M)		**$183,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $123,000
Total Annualized Cost		**$306,000**

Utilities Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979) 0
electricity(kWh)/day (U.S.EPA 1979) 2880

Table C.52
Collection of Continuous Digester Vent Gases and Incineration
OAQPS Costing Methodology ($Can 1994) 1000 TPD Pulp Mill
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,009,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$485,100
Direct installation cost	0.5*PEC	$242,600
Engineering	0.1*PEC	$48,500
Construction overhead	0.05*PEC	$24,300
Contractor Fees	0.1*PEC	$48,500
Start-up	0.02*PEC	$9,700
Performance test	0.01*PEC	$4,900
Contingencies	0.3*PEC	$145,500
Total Capital Cost	**2.08*PEC**	**$1,009,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Overhead (60% of labour and maintenance costs)		$25,400
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$20,200
Property taxes	1% of TCC	$10,100
Insurance	1% of TCC	$10,100
Operating and Maintenance Cost (O&M)		**$164,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $164,000
Total Annualized Cost		**$328,000**

Utilities	Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979)	0
electricity(kWh)/day (U.S.EPA 1979)	2880

Table C.53
Collection of Continuous Digester Vent Gases and Incineration
OAQPS Costing Methodology ($Can 1994) 1500 TPD Pulp Mill
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,261,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$606,300
Direct installation cost	0.5*PEC	$303,200
Engineering	0.1*PEC	$60,600
Construction overhead	0.05*PEC	$30,300
Contractor Fees	0.1*PEC	$60,600
Start-up	0.02*PEC	$12,100
Performance test	0.01*PEC	$6,100
Contingencies	0.3*PEC	$181,900
Total Capital Cost	**2.08*PEC**	**$1,261,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Overhead (60% of labour and maintenance costs)		$25,400
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$25,200
Property taxes	1% of TCC	$12,600
Insurance	1% of TCC	$12,600
Operating and Maintenance Cost (O&M)		**$174,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$205,000
Total Annualized Cost		**$379,000**

Utilities	Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979)	0
electricity(kWh)/day (U.S.EPA 1979)	2880

Table C.54
Incineration of chip bin continuous digester in recovery or power boiler
OAQPS Costing Methodology ($Can 1994) 1000 TPD Pulp Mill
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$2,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$961,500
Direct installation cost	0.5*PEC	$480,800
Engineering	0.1*PEC	$96,200
Construction overhead	0.05*PEC	$48,100
Contractor Fees	0.1*PEC	$96,200
Start-up	0.02*PEC	$19,200
Performance test	0.01*PEC	$9,600
Contingencies	0.3*PEC	$288,500
Total Capital Cost	**2.08*PEC**	**$2,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$100,000
Overhead (60% of labour and maintenance costs)		$73,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.059/kWh	$55,800
Administrative	2% of TCC	$40,000
Property taxes	1% of TCC	$20,000
Insurance	1% of TCC	$20,000
Operating and Maintenance Cost (O&M)		**$332,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$326,000
Total Annualized Cost		**$658,000**

Utilities

fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979)	0
electricity(kWh)/day (U.S.EPA 1979)	2880

Table C.55
Lime Kiln - process control - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	**$189,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$90,900
Direct installation cost	0.5*PEC	$45,500
Engineering	0.1*PEC	$9,100
Construction overhead	0.05*PEC	$4,500
Contractor Fees	0.1*PEC	$9,100
Start-up	0.02*PEC	$1,800
Performance test	0.01*PEC	$900
Contingencies	0.3*PEC	$27,300
Total Capital Cost	**2.08*PEC**	**$189,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$153,900
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$3,800
Property taxes	1% of TCC	$1,900
Insurance	1% of TCC	$1,900
Operating and Maintenance Cost (O&M)		**$218,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $31,000
Total Annualized Cost		**$249,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities

fuel (Btu/day)*	142
electricity (kWh/day)*	1075

Table C.56
Lime Kiln - process control - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	**$252,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$121,200
Direct installation cost	0.5*PEC	$60,600
Engineering	0.1*PEC	$12,100
Construction overhead	0.05*PEC	$6,100
Contractor Fees	0.1*PEC	$12,100
Start-up	0.02*PEC	$2,400
Performance test	0.01*PEC	$1,200
Contingencies	0.3*PEC	$36,400
Total Capital Cost	**2.08*PEC**	**$252,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$153,900
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$5,000
Property taxes	1% of TCC	$2,500
Insurance	1% of TCC	$2,500
Operating and Maintenance Cost (O&M)		**$220,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $41,000
Total Annualized Cost		**$261,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities

fuel (Btu/day)*	142
electricity (kWh/day)*	1075

Table C.57
Lime Kiln - process control - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	**$504,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$242,300
Direct installation cost	0.5*PEC	$121,200
Engineering	0.1*PEC	$24,200
Construction overhead	0.05*PEC	$12,100
Contractor Fees	0.1*PEC	$24,200
Start-up	0.02*PEC	$4,800
Performance test	0.01*PEC	$2,400
Contingencies	0.3*PEC	$72,700
Total Capital Cost	**2.08*PEC**	**$504,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$153,900
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$10,100
Property taxes	1% of TCC	$5,000
Insurance	1% of TCC	$5,000
Operating and Maintenance Cost (O&M)		**$230,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $82,000
Total Annualized Cost		**$312,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities

fuel (Btu/day)*	142
electricity (kWh/day)*	1075

Table C.58
Lime Kiln Process Control
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$500,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$240,400
Direct installation cost	0.5*PEC	$120,200
Engineering	0.1*PEC	$24,000
Construction overhead	0.05*PEC	$12,000
Contractor Fees	0.1*PEC	$24,000
Start-up	0.02*PEC	$4,800
Performance test	0.01*PEC	$2,400
Contingencies	0.3*PEC	$72,100
Total Capital Cost	**2.08*PEC**	**$500,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$25,000
Overhead (60% of labour and maintenance costs)		$28,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$0
Administrative	2% of TCC	$10,000
Property taxes	1% of TCC	$5,000
Insurance	1% of TCC	$5,000
Operating and Maintenance Cost (O&M)		**$96,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$81,000
Total Annualized Cost		**$177,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day ?
electricity(kWh)/day ?

Table C.59
Lime Kiln - mud washing capacity - low retrofit penalty - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,210,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$581,700
Direct installation cost	0.5*PEC	$290,900
Engineering	0.1*PEC	$58,200
Construction overhead	0.05*PEC	$29,100
Contractor Fees	0.1*PEC	$58,200
Start-up	0.02*PEC	$11,600
Performance test	0.01*PEC	$5,800
Contingencies	0.3*PEC	$174,500
Total Capital Cost	**2.08*PEC**	**$1,210,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$24,200
Property taxes	1% of TCC	$12,100
Insurance	1% of TCC	$12,100
Operating and Maintenance Cost (O&M)		**$105,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$197,000
Total Annualized Cost		**$302,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 1075

Table C.60
Lime Kiln - mud washing capacity - low retrofit penalty - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	**$1,841,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$885,100
Direct installation cost	0.5*PEC	$442,600
Engineering	0.1*PEC	$88,500
Construction overhead	0.05*PEC	$44,300
Contractor Fees	0.1*PEC	$88,500
Start-up	0.02*PEC	$17,700
Performance test	0.01*PEC	$8,900
Contingencies	0.3*PEC	$265,500
Total Capital Cost	**2.08*PEC**	**$1,841,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$36,800
Property taxes	1% of TCC	$18,400
Insurance	1% of TCC	$18,400
Operating and Maintenance Cost (O&M)		**$130,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$299,000
Total Annualized Cost		**$429,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	1075

Table C.61
Lime Kiln - mud washing capacity - low retrofit penalty - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	**$2,396,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,151,900
Direct installation cost	0.5*PEC	$576,000
Engineering	0.1*PEC	$115,200
Construction overhead	0.05*PEC	$57,600
Contractor Fees	0.1*PEC	$115,200
Start-up	0.02*PEC	$23,000
Performance test	0.01*PEC	$11,500
Contingencies	0.3*PEC	$345,600
Total Capital Cost	**2.08*PEC**	**$2,396,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$47,900
Property taxes	1% of TCC	$24,000
Insurance	1% of TCC	$24,000
Operating and Maintenance Cost (O&M)		**$152,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $390,000
Total Annualized Cost		**$542,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	1075

Table C.62
Lime Kiln - mud washing capacity - high retrofit penalty - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	$2,421,000

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,163,900
Direct installation cost	0.5*PEC	$582,000
Engineering	0.1*PEC	$116,400
Construction overhead	0.05*PEC	$58,200
Contractor Fees	0.1*PEC	$116,400
Start-up	0.02*PEC	$23,300
Performance test	0.01*PEC	$11,600
Contingencies	0.3*PEC	$349,200
Total Capital Cost	**2.08*PEC**	**$2,421,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$48,400
Property taxes	1% of TCC	$24,200
Insurance	1% of TCC	$24,200
Operating and Maintenance Cost (O&M)		**$153,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$394,000
Total Annualized Cost		**$547,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities
fuel (Btu/day)* 0
electricity (kWh/day)* 1075

Table C.63
Lime Kiln - mud washing capacity - high retrofit penalty - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	**$3,682,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,770,200
Direct installation cost	0.5*PEC	$885,100
Engineering	0.1*PEC	$177,000
Construction overhead	0.05*PEC	$88,500
Contractor Fees	0.1*PEC	$177,000
Start-up	0.02*PEC	$35,400
Performance test	0.01*PEC	$17,700
Contingencies	0.3*PEC	$531,100
Total Capital Cost	**2.08*PEC**	**$3,682,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$73,600
Property taxes	1% of TCC	$36,800
Insurance	1% of TCC	$36,800
Operating and Maintenance Cost (O&M)		**$204,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $599,000
Total Annualized Cost		**$803,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	1075

Table C.64
Lime Kiln - mud washing capacity - high retrofit penalty - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 an corrected to ($Can 1994)

Total Capital Cost (TCC)	**$4,791,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$2,303,400
Direct installation cost	0.5*PEC	$1,151,700
Engineering	0.1*PEC	$230,300
Construction overhead	0.05*PEC	$115,200
Contractor Fees	0.1*PEC	$230,300
Start-up	0.02*PEC	$46,100
Performance test	0.01*PEC	$23,000
Contingencies	0.3*PEC	$691,000
Total Capital Cost	**2.08*PEC**	**$4,791,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$13,600
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh*	$20,100
Administrative	2% of TCC	$95,800
Property taxes	1% of TCC	$47,900
Insurance	1% of TCC	$47,900
Operating and Maintenance Cost (O&M)		**$248,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$779,000
Total Annualized Cost		**$1,027,000**

* U.S.EPA 1979 - Not allocated any charges for maintenance and repair

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	1075

Table C.65
Lime mud recycle
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$50,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$24,000
Direct installation cost	0.5*PEC	$12,000
Engineering	0.1*PEC	$2,400
Construction overhead	0.05*PEC	$1,200
Contractor Fees	0.1*PEC	$2,400
Start-up	0.02*PEC	$500
Performance test	0.01*PEC	$200
Contingencies	0.3*PEC	$7,200
Total Capital Cost	**2.08*PEC**	**$50,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$2,500
Overhead (60% of labour and maintenance costs)		$15,100
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$0
Administrative	2% of TCC	$1,000
Property taxes	1% of TCC	$500
Insurance	1% of TCC	$500
Operating and Maintenance Cost (O&M)		**$42,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$8,000
Total Annualized Cost		**$50,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day ?
electricity(kWh)/day ?

Table C.66
Large lime mud precoat filter
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$3,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,442,300
Direct installation cost	0.5*PEC	$721,200
Engineering	0.1*PEC	$144,200
Construction overhead	0.05*PEC	$72,100
Contractor Fees	0.1*PEC	$144,200
Start-up	0.02*PEC	$28,800
Performance test	0.01*PEC	$14,400
Contingencies	0.3*PEC	$432,700
Total Capital Cost	**2.08*PEC**	**$3,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$150,000
Overhead (60% of labour and maintenance costs)		$103,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$0
Administrative	2% of TCC	$60,000
Property taxes	1% of TCC	$30,000
Insurance	1% of TCC	$30,000
Operating and Maintenance Cost (O&M)		**$396,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$488,000
Total Annualized Cost		**$884,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day ?
electricity(kWh)/day ?

Table C.67
Emissions from condensate stripper destruction in Lime Kiln - 500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$41,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$19,700
Direct installation cost	0.5*PEC	$9,900
Engineering	0.1*PEC	$2,000
Construction overhead	0.05*PEC	$1,000
Contractor Fees	0.1*PEC	$2,000
Start-up	0.02*PEC	$400
Performance test	0.01*PEC	$200
Contingencies	0.3*PEC	$5,900
Total Capital Cost	**2.08*PEC**	**$41,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	0*	$0
Supervisory Labour	0*	$0
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$0
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh	$15,700
Administrative	2% of TCC	$800
Property taxes	1% of TCC	$400
Insurance	1% of TCC	$400
Operating and Maintenance (O&M)		**$17,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $7,000
Total Annualized Cost		**$41,000**

* U.S.EPA 1979 - Operating and Maintenance Costs included in Steam Stripper Costs

Notes

Utilities	
fuel (Btu/day)*	0
electricity (kWh/day)*	840

Table C.68
Emissions from condensate stripper destruction in Lime Kiln - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$57,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$27,400
Direct installation cost	0.5*PEC	$13,700
Engineering	0.1*PEC	$2,700
Construction overhead	0.05*PEC	$1,400
Contractor Fees	0.1*PEC	$2,700
Start-up	0.02*PEC	$500
Performance test	0.01*PEC	$300
Contingencies	0.3*PEC	$8,200
Total Capital Cost	**2.08*PEC**	**$57,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	0*	$0
Supervisory Labour	0*	$0
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$0
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh	$15,700
Administrative	2% of TCC	$1,100
Property taxes	1% of TCC	$600
Insurance	1% of TCC	$600
Operating and Maintenance (O&M)		**$18,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$9,000
Total Annualized Cost		**$45,000**

* U.S.EPA 1979 - Operating and Maintenance Costs included in Steam Stripper Costs

Notes

Utilities

fuel (Btu/day)*	0
electricity (kWh/day)*	840

Table C.69
Emissions from condensate stripper destruction in Lime Kiln - 1500 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($Can 1994)

Total Capital Cost (TCC)	**$71,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$34,100
Direct installation cost	0.5*PEC	$17,100
Engineering	0.1*PEC	$3,400
Construction overhead	0.05*PEC	$1,700
Contractor Fees	0.1*PEC	$3,400
Start-up	0.02*PEC	$700
Performance test	0.01*PEC	$300
Contingencies	0.3*PEC	$10,200
Total Capital Cost	**2.08*PEC**	**$71,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	0*	$0
Supervisory Labour	0*	$0
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$0
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh	$15,700
Administrative	2% of TCC	$1,400
Property taxes	1% of TCC	$700
Insurance	1% of TCC	$700
Operating and Maintenance (O&M)		**$19,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$12,000
Total Annualized Cost		**$50,000**

* U.S.EPA 1979 - Operating and Maintenance Costs included in Steam Stripper Costs

Notes

Utilities	
fuel (Btu/day)*	0
electricity (kWh/day)*	840

Table C.70
Switch from weak wash to caustic on the smelt dissolving tank scrubber
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$200,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$96,200
Direct installation cost	0.5*PEC	$48,100
Engineering	0.1*PEC	$9,600
Construction overhead	0.05*PEC	$4,800
Contractor Fees	0.1*PEC	$9,600
Start-up	0.02*PEC	$1,900
Performance test	0.01*PEC	$1,000
Contingencies	0.3*PEC	$28,900
Total Capital Cost	**2.08*PEC**	**$200,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Costs	5% TCC	$10,000
Overhead (60% of labour and maintenance costs)		$19,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$0
Administrative	2% of TCC	$4,000
Property taxes	1% of TCC	$2,000
Insurance	1% of TCC	$2,000
Chemical costs		$200,000
Operating and Maintenance Cost (O&M)		**$260,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$33,000
Total Annualized Cost		**$293,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day 0
electricity(kWh)/day 0

Table C.71
Small scrubber (sewer vent gas)
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$300,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$144,200
Direct installation cost	0.5*PEC	$72,100
Engineering	0.1*PEC	$14,400
Construction overhead	0.05*PEC	$7,200
Contractor Fees	0.1*PEC	$14,400
Start-up	0.02*PEC	$2,900
Performance test	0.01*PEC	$1,400
Contingencies	0.3*PEC	$43,300
Total Capital Cost	**2.08*PEC**	**$300,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$15,000
Overhead (60% of labour and maintenance costs)		$22,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$100
Administrative	2% of TCC	$6,000
Property taxes	1% of TCC	$3,000
Insurance	1% of TCC	$3,000
Operating and Maintenance Cost (O&M)		**$72,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $49,000
Total Annualized Cost		**$121,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day 0
electricity(kWh)/day (estimated based on OAQPS) 4

Table C.72
Large scrubber (brown stock washers hood vents and other vent gases)
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	$3,000,000	hidden factor

Cost Item	Cost Factor	Value	
Purchase equipment cost (PEC)	PEC	$1,442,300	1
Direct installation cost	0.5*PEC	$721,200	0.5
Engineering	0.1*PEC	$144,200	0.1
Construction overhead	0.05*PEC	$72,100	0.05
Contractor Fees	0.1*PEC	$144,200	0.1
Start-up	0.02*PEC	$28,800	0.02
Performance test	0.01*PEC	$14,400	0.01
Contingencies	0.3*PEC	$432,700	0.3
Total Capital Cost	**2.08*PEC**	**$3,000,000**	2.08

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value	hidden factor
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700	40
Supervisory Labour	15% of operating labour	$3,000	0.15
Maintenance Cost	5% TCC	$150,000	0.05
Overhead (60% of labour and maintenance costs)		$103,600	0.6
Utilities (fuel)	$3.30/1000ft^3	$0	3.3
Utilities (electricity)	$0.059/kwh	$23,600	0.059
Administrative	2% of TCC	$60,000	0.02
Property taxes	1% of TCC	$30,000	0.01
Insurance	1% of TCC	$30,000	0.01
Operating and Maintenance Cost (O&M)		**$420,000**	
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$488,000	0.16275
Total Annualized Cost		**$908,000**	

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day 0
electricity(kWh)/day (estimated based on OAQPS) 1218

Table C.73
Recovery boiler scrubber
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$10,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$4,807,700
Direct installation cost	0.5*PEC	$2,403,900
Engineering	0.1*PEC	$480,800
Construction overhead	0.05*PEC	$240,400
Contractor Fees	0.1*PEC	$480,800
Start-up	0.02*PEC	$96,200
Performance test	0.01*PEC	$48,100
Contingencies	0.3*PEC	$1,442,300
Total Capital Cost	**2.08*PEC**	**$10,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$500,000
Overhead (60% of labour and maintenance costs)		$313,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$100,300
Administrative	2% of TCC	$200,000
Property taxes	1% of TCC	$100,000
Insurance	1% of TCC	$100,000
Operating and Maintenance Cost (O&M)		**$1,337,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $1,628,000
Total Annualized Cost		**$2,965,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day 0
electricity(kWh)/day (estimated based on OAQPS) 5175

Table C.74
Recovery boiler scrubber
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by H.A.Simons et al 1994

Total Capital Cost (TCC)	**$7,800,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$3,750,000
Direct installation cost	0.5*PEC	$1,875,000
Engineering	0.1*PEC	$375,000
Construction overhead	0.05*PEC	$187,500
Contractor Fees	0.1*PEC	$375,000
Start-up	0.02*PEC	$75,000
Performance test	0.01*PEC	$37,500
Contingencies	0.3*PEC	$1,125,000
Total Capital Cost	**2.08*PEC**	**$7,800,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$390,000
Overhead (60% of labour and maintenance costs)		$247,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$100,300
Administrative	2% of TCC	$156,000
Property taxes	1% of TCC	$78,000
Insurance	1% of TCC	$78,000
Operating and Maintenance Cost (O&M)		**$1,073,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$1,269,000
Total Annualized Cost		**$2,342,000**

Utilities

fuel (1000 ft^3 = 1 MBtu) (MBtu)/day	0
electricity(kWh)/day (estimated based on OAQPS)	5175

Table C.75
Dissolving Tank Vent Scrubber and Modifications
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Rainy River Forest Product Inc.

Total Capital Cost (TCC)	**$1,656,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$796,200
Direct installation cost	0.5*PEC	$398,100
Engineering	0.1*PEC	$79,600
Construction overhead	0.05*PEC	$39,800
Contractor Fees	0.1*PEC	$79,600
Start-up	0.02*PEC	$15,900
Performance test	0.01*PEC	$8,000
Contingencies	0.3*PEC	$238,900
Total Capital Cost	**2.08*PEC**	**$1,656,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$82,800
Overhead (60% of labour and maintenance costs)		$63,300
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$9,400
Administrative	2% of TCC	$33,100
Property taxes	1% of TCC	$16,600
Insurance	1% of TCC	$16,600
Operating and Maintenance Cost (O&M)		**$245,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$270,000
Total Annualized Cost		**$515,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 487

Table C.76
Lime kiln stack venturi scrubber
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Rainy River Forest Products Inc.

Total Capital Cost (TCC)	**$4,141,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$1,990,900
Direct installation cost	0.5*PEC	$995,500
Engineering	0.1*PEC	$199,100
Construction overhead	0.05*PEC	$99,500
Contractor Fees	0.1*PEC	$199,100
Start-up	0.02*PEC	$39,800
Performance test	0.01*PEC	$19,900
Contingencies	0.3*PEC	$597,300
Total Capital Cost	**2.08*PEC**	**$4,141,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$207,100
Overhead (60% of labour and maintenance costs)		$137,900
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$14,800
Administrative	2% of TCC	$82,800
Property taxes	1% of TCC	$41,400
Insurance	1% of TCC	$41,400
Operating and Maintenance Cost (O&M)		**$548,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $674,000
Total Annualized Cost		**$1,222,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 764

Table C.77
Bleach plant stack scrubber
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Rainy River Forest Product Inc.

Total Capital Cost (TCC)	**$2,588,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$1,244,200
Direct installation cost	0.5*PEC	$622,100
Engineering	0.1*PEC	$124,400
Construction overhead	0.05*PEC	$62,200
Contractor Fees	0.1*PEC	$124,400
Start-up	0.02*PEC	$24,900
Performance test	0.01*PEC	$12,400
Contingencies	0.3*PEC	$373,300
Total Capital Cost	**2.08*PEC**	**$2,588,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$129,400
Overhead (60% of labour and maintenance costs)		$91,300
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$11,200
Administrative	2% of TCC	$51,800
Property taxes	1% of TCC	$25,900
Insurance	1% of TCC	$25,900
Operating and Maintenance Cost (O&M)		**$358,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$421,000
Total Annualized Cost		**$779,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 578

Table C.78
Tall oil plant vent scrubber
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Rainy River Forest Products Inc.

Total Capital Cost (TCC)	**$414,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$199,000
Direct installation cost	0.5*PEC	$99,500
Engineering	0.1*PEC	$19,900
Construction overhead	0.05*PEC	$10,000
Contractor Fees	0.1*PEC	$19,900
Start-up	0.02*PEC	$4,000
Performance test	0.01*PEC	$2,000
Contingencies	0.3*PEC	$59,700
Total Capital Cost	**2.08*PEC**	**$414,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$20,700
Overhead (60% of labour and maintenance costs)		$26,000
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$800
Administrative	2% of TCC	$8,300
Property taxes	1% of TCC	$4,100
Insurance	1% of TCC	$4,100
Operating and Maintenance Cost (O&M)		**$87,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$67,000
Total Annualized Cost		**$154,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 42

Table C.79
Effluent building vent scrubber
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Rainy River Forest Products Inc.

Total Capital Cost (TCC)	**$414,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$199,000
Direct installation cost	0.5*PEC	$99,500
Engineering	0.1*PEC	$19,900
Construction overhead	0.05*PEC	$10,000
Contractor Fees	0.1*PEC	$19,900
Start-up	0.02*PEC	$4,000
Performance test	0.01*PEC	$2,000
Contingencies	0.3*PEC	$59,700
Total Capital Cost	**2.08*PEC**	**$414,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$20,700
Overhead (60% of labour and maintenance costs)		$26,000
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$100
Administrative	2% of TCC	$8,300
Property taxes	1% of TCC	$4,100
Insurance	1% of TCC	$4,100
Operating and Maintenance Cost (O&M)		**$86,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $67,000
Total Annualized Cost		**$153,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 4

Table C.80
Collection of Brown Stock Washer Gases to Vent from Boiler Stack
1000 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell (1994)

Total Capital Cost (TCC)	**$1,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$480,800
Direct installation cost	0.5*PEC	$240,400
Engineering	0.1*PEC	$48,100
Construction overhead	0.05*PEC	$24,000
Contractor Fees	0.1*PEC	$48,100
Start-up	0.02*PEC	$9,600
Performance test	0.01*PEC	$4,800
Contingencies	0.3*PEC	$144,200
Total Capital Cost	**2.08*PEC**	**$1,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$50,000
Overhead (60% of labour and maintenance costs)		$43,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$60,700
Administrative	2% of TCC	$20,000
Property taxes	1% of TCC	$10,000
Insurance	1% of TCC	$10,000
Operating and Maintenance Cost (O&M)	Sum of above	**$217,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$163,000
Total Annualized Cost	O&M + capital recovery	**$380,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979) 0
electricity (kWh/y) - (U.S.EPA 1993a) 1028676 90% of total

Btu-kWh converstion factor 0.00029
stainless steel multiplier 1.3
purchased equipment cost carbon steel $257,108
purchased equipment cost stainless steel $334,240
retrofit cost factor (estimated) 1.44
purchased equipment cost - stainless steel/retrofit factor $480,800

Table C.81
Lime Kiln
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by U.S.EPA 1979 and corrected to ($CAN 1994)

Total Capital Cost (TCC)	**$7,565,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$3,637,000
Direct installation cost	0.5*PEC	$1,818,500
Engineering	0.1*PEC	$363,700
Construction overhead	0.05*PEC	$181,900
Contractor Fees	0.1*PEC	$363,700
Start-up	0.02*PEC	$72,700
Performance test	0.01*PEC	$36,400
Contingencies	0.3*PEC	$1,091,100
Total Capital Cost	**2.08*PEC**	**$7,565,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$378,300
Overhead (60% of labour and maintenance costs)		$240,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$0
Administrative	2% of TCC	$151,300
Property taxes	1% of TCC	$75,700
Insurance	1% of TCC	$75,700
Operating and Maintenance Cost (O&M)		**$944,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$1,231,000
Total Annualized Cost		**$2,175,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day 142
electricity(kWh)/day 1075

Table C.82
Lime Kiln with precipitator, and new lime mud filter
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$30,000,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$14,423,100
Direct installation cost	0.5*PEC	$7,211,600
Engineering	0.1*PEC	$1,442,300
Construction overhead	0.05*PEC	$721,200
Contractor Fees	0.1*PEC	$1,442,300
Start-up	0.02*PEC	$288,500
Performance test	0.01*PEC	$144,200
Contingencies	0.3*PEC	$4,326,900
Total Capital Cost	**2.08*PEC**	**$30,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$1,500,000
Overhead (60% of labour and maintenance costs)		$913,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$0
Administrative	2% of TCC	$600,000
Property taxes	1% of TCC	$300,000
Insurance	1% of TCC	$300,000
Operating and Maintenance Cost (O&M)		**$3,636,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$4,883,000
Total Annualized Cost		**$8,519,000**

Utilities

fuel (1000 ft^3 = 1 MBtu) (MBtu)/day	142
electricity(kWh)/day	1075

Table C.83
Replacement of Vacuum BSW with Displacement BSW
1000 TPD Pulp Mill
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell (1994)

Total Capital Cost (TCC)	**$20,000,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$9,615,400
Direct installation cost	0.5*PEC	$4,807,700
Engineering	0.1*PEC	$961,500
Construction overhead	0.05*PEC	$480,800
Contractor Fees	0.1*PEC	$961,500
Start-up	0.02*PEC	$192,300
Performance test	0.01*PEC	$96,200
Contingencies	0.3*PEC	$2,884,600
Total Capital Cost	**2.08*PEC**	**$20,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% of TCC	$1,000,000
Overhead (60% of labour and maintenance costs)		$613,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$60,700
Administrative	2% of TCC	$400,000
Property taxes	1% of TCC	$200,000
Insurance	1% of TCC	$200,000
Operating and Maintenance Cost (O&M)	Sum of above	**$2,497,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$3,255,000
Total Annualized Cost	O&M + capital recovery	**$5,752,000**

Utilities
fuel (1000 ft^3 = 1 MBtu) (MBtu)/day (U.S.EPA 1979) 0
electricity (kWh/y) - (U.S.EPA 1993a) 1028676 90% of total

Btu-kWh converstion factor	0.00029
stainless steel multiplier	1.3
purchased equipment cost carbon steel	$5,141,835
purchased equipment cost stainless steel	$6,684,386
retrofit cost factor (estimated)	1.44
purchased equipment cost - stainless steel/retrofit factor	$9,615,400

Table C.84
Emissions from condensate stripper destruction in Lime Kiln - 1000 TPD
OAQPS Costing Methodology ($Can 1994)
Capital Cost reported by Blackwell 1994

Total Capital Cost (TCC)	**$400,000**

Cost Item	Cost Factor	Value
Purchase equipment cost (PEC)	PEC	$192,300
Direct installation cost	0.5*PEC	$96,200
Engineering	0.1*PEC	$19,200
Construction overhead	0.05*PEC	$9,600
Contractor Fees	0.1*PEC	$19,200
Start-up	0.02*PEC	$3,800
Performance test	0.01*PEC	$1,900
Contingencies	0.3*PEC	$57,700
Total Capital Cost	**2.08*PEC**	**$400,000**

Total Annualized Cost operating days/year 328.5

Cost Item	Cost Factor	Value
Operating labour (0.5 hours/8 hour shift)	0*	$0
Supervisory Labour	0*	$0
Maintentance Labour (0.5 hours/8 hour shift)	0*	$0
Maintenance Materials	0*	$0
Overhead (60% of labour and maintenance costs)		$0
Utilities (fuel)	$3.30/MBtu	$0
Utilities (electricity)	$0.057/kWh	$15,700
Administrative	2% of TCC	$8,000
Property taxes	1% of TCC	$4,000
Insurance	1% of TCC	$4,000
Operating and Maintenance (O&M)		**$32,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $65,000
Total Annualized Cost		**$129,000**

* U.S.EPA 1979 - Operating and Maintenance Costs included in Steam Stripper Costs

Notes

Utilities	
fuel (Btu/day)*	0
electricity (kWh/day)*	840

Table C.85
Small Scrubber (clarifier vents, turpentine decanter vent)
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$500,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$240,400
Direct installation cost	0.5*PEC	$120,200
Engineering	0.1*PEC	$24,000
Construction overhead	0.05*PEC	$12,000
Contractor Fees	0.1*PEC	$24,000
Start-up	0.02*PEC	$4,800
Performance test	0.01*PEC	$2,400
Contingencies	0.3*PEC	$72,100
Total Capital Cost	**2.08*PEC**	**$500,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$25,000
Overhead (60% of labour and maintenance costs)		$28,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$100
Administrative	2% of TCC	$10,000
Property taxes	1% of TCC	$5,000
Insurance	1% of TCC	$5,000
Operating and Maintenance Cost (O&M)		**$96,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	 $81,000
Total Annualized Cost		**$177,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 4

Table C.86
Large scrubber (black liquor storage tanks)
OAQPS Costing Methodology ($Can 1994)
Capital Cost Reported by Blackwell 1994

Total Capital Cost (TCC)	**$1,000,000**

Cost Item	**Cost Factor**	**Value**
Purchase equipment cost (PEC)	PEC	$480,800
Direct installation cost	0.5*PEC	$240,400
Engineering	0.1*PEC	$48,100
Construction overhead	0.05*PEC	$24,000
Contractor Fees	0.1*PEC	$48,100
Start-up	0.02*PEC	$9,600
Performance test	0.01*PEC	$4,800
Contingencies	0.3*PEC	$144,200
Total Capital Cost	**2.08*PEC**	**$1,000,000**

Total Annualized Cost operating days/year 328.5

Cost Item	**Cost Factor**	**Value**
Operating labour (0.5 hours/8 hour shift)	$40/hour	$19,700
Supervisory Labour	15% of operating labour	$3,000
Maintenance Cost	5% TCC	$50,000
Overhead (60% of labour and maintenance costs)		$43,600
Utilities (fuel)	$3.30/1000ft^3	$0
Utilities (electricity)	$0.059/kwh	$23,600
Administrative	2% of TCC	$20,000
Property taxes	1% of TCC	$10,000
Insurance	1% of TCC	$10,000
Operating and Maintenance Cost (O&M)		**$180,000**
Capital recovery 10 year @ 10%	capital recovery factor * TCC 0.16275*TCC	$163,000
Total Annualized Cost		**$343,000**

Utilities
fuel (1000 ft^3 = 1 MBtu)
electricity (kWh/y) (estimated based on OAQPS) 1218

APPENDIX D:
MEASURED VISIBLE EMISSIONS AT COKE OVEN BATTERIES IN THE UNITED STATES

TABLE 4-4. STATISTICAL RESULTS FROM CHARGING DATA

Company	Battery	Arithmetic average (s/charge)	Log average (s/charge)	95-percent level (log average, s/charge)
U.S. Steel, Clairton[a]	16	1.0	0.5	1.2
	17	1.2	0.8	1.7
U.S. Steel, Fairfield	9	5.4	4.0	6.7
CF&I, Pueblo[a]	B	5.4	4.5	7.4
U.S. Steel, Clairton[a]	1	8.6	4.8	7.9
	22	6.6	5.1	8.3
Shenango, Neville Island	3	6.1	5.1	8.4
J&L, Pittsburgh	P2	7.3	5.6	9.1
	P4	6.2	5.6	9.1
U.S. Steel, Clairton[a]	10	8.8	6.0	9.8
	19	6.8	6.1	9.9
Shenango, Neville Island	4	6.6	6.2	10.0
U.S. Steel, Fairfield	6	10.0	6.8	10.9
U.S. Steel, Clairton[a]	3	7.8	6.9	11.2
	7	7.6	7.3	11.6
	21	13.1	7.3	11.7
	9	8.4	7.5	12.0
Lone Star Steel	C[b]	7.4	6.6	12.0
Bethlehem Steel, Burns Harbor	2[b]	10.8	6.9	12.5
U.S. Steel, Clairton[a]	2	9.0	7.7	12.4
	8	8.9	8.1	13.0
	20	12.0	8.1	13.0
U.S. Steel, Gary	1[b]	13.0	8.4	15.0
National Steel, Weirton	1[b]	11.9	9.0	16.1
U.S. Steel, Clairtor[a]	11	11.6	10.1	16.1

[a]These batteries used the optimization of stage charging described in Section 4.1.1.3.

[b]Tall (5- or 6-meter) batteries.

Average
7.5

TABLE 4-10. SUMMARY OF DOOR LEAK DATA[a]

Company	Battery	Date	Average PLD	Range PLD	Number of observations
U.S. Steel, Clairton[20]	3	2/80	0.8	0 - 1.6	4
	1	8/79	1.0	0 - 2.3	7
	2	8/79	2.2	0 - 5.5	7
	7	2/80	2.9	0 - 5.5	4
National Steel, Weirton[24]	1[b]	6/82	2.9	1.2 - 4.8	5
U.S. Steel, Clairton[20]	21	8/79	3.0	1.1 - 5.7	5
CF&I, Pueblo[80]	C	3/78	3.2	1.1 - 6.4	27
U.S. Steel, Clairton[20]	22	8/79	3.5	2.3 - 5.2	6
	19	8/79	3.9	3.4 - 4.6	5
U.S. Steel, Fairfield[27]	9[c]	6/79	3.9	2.7 - 4.8	6
CF&I, Pueblo[80]	B	3/78	4.3	0.8 - 9.2	28
U.S. Steel, Clairton[20]	20	8/79	4.5	2.3 - 7.5	9
	16	2/80	5.0	4.2 - 6.7	4
	10	2/80	5.8	4.8 - 7.1	2
CF&I, Pueblo[80]	D	3/78	5.9	1.1 - 16.1	27
U.S. Steel, Clairton[20]	8	2/80	6.1	5.5 - 6.3	4
	17	2/80	6.2	4.9 - 8.2	4
U.S. Steel, Fairfield[27]	2[b]	6/79	7.2	3.0 - 13.0	7
U.S. Steel, Clairton[20]	11	2/80	8.9	5.5 - 14.1	3
	9	2/80	9.4	3.9 - 16.4	4

[a]The batteries at CF&I and U.S. Steel, Clairton have implemented the modified seal technology.

[b]A 6-meter battery without the modified seal technology.

[c]A rebuilt battery without the modified seal technology.

Average
4.5

TABLE 4-15. SUMMARY OF LID LEAK DATA

Company	Battery	Date	Average PLL	Range PLL	Number of observations
U.S. Steel, Clairton[20 88]	1	8/78	0.3	0 - 0.8	9
		8/79	0.2	0 - 0.4	5
		2/80	0.2	0 - 0.4	4
	2	8/78	0.2	0 - 0.8	9
		8/79	0.4	0 - 2	5
		2/80	0.3	0 - 1.2	4
	3	8/78	1.4	0 - 4.7	9
		8/79	0.5	0 - 2	5
		2/80	0.3	0 - 1.2	4
	7	8/78	0.9	0.4 - 2.0	8
		8/79	1.6	1.2 - 2.4	3
		2/80	0.4	0 - 0.8	4
	8	8/78	0.3	0 - 0.8	9
		8/79	0.1	0 - 0.4	3
		2/80	0.3	0 - 0.8	4
	9	8/78	0.9	0 - 2.0	9
		8/79	0.8	0.4 - 1.2	3
		2/80	0.4	0 - 0.8	4
	10	8/78	0.5	0 - 1.2	9
		8/79	0.7	0.4 - 1.2	3
		2/80	0	-	3
	11	8/78	0.5	0 - 1.6	9
		8/79	0	-	3
		2/80	0.3	0 - 0.4	3
	12	8/78	0.5	0 - 1.6	9
		8/79	0	-	3
	12A	8/78	0.6	0 - 2.6	9
	13	8/78	0.4	0 - 1.2	9
	14	8/78	0.3	0 - 1.6	9
	16	8/78	0.2	0 - 0.4	9
		8/79	0.1	0 - 0.4	8
		2/80	0.1	0 - 0.4	3

(continued)

TABLE 4-15. (continued)

Company	Battery	Date	Average PLL	Range PLL	Number of observations
	17	8/78	0.2	0 - 1.2	9
		8/79	0.2	0 - 0.8	7
		2/80	0.1	0 - 0.4	3
	19	8/78	0.4	0 - 1.1	9
		8/79	1.2	0 - 3.5	6
		2/80	0.4	0 - 0.9	5
	20	8/79	0.9	0 - 1.8	7
		2/80	0.7	0 - 1.5	5
	21	8/78	0.2	0 - 0.6	9
		8/79	0.5	0 - 0.9	6
		2/80	0.4	0 - 0.8	4
	22	8/78	0.2	0 - 0.6	9
		8/79	0.9	0 - 1.8	7
		2/80	0.2	0 - 0.9	5
U.S Steel, Fairfield[27]	2	6/79	0.1	0 - 0.5	6
	6	6/79	1.8	-	1
	9	6/79	0	-	6
Kaiser, Fontana[16]	F	5/79	0	-	8
	G	5/79	0.2	0 - 1.7	8

Average
0.44

TABLE 4-16. SUMMARY OF OFFTAKE LEAK DATA

Company	Battery	Date	Average PLO	Range PLO	Number of observations
U.S. Steel, Clairton[20]	1	8/79	0.7	0 - 3.5	7
	2	8/79	0.8	0 - 2.5	7
	3	8/79	0.9	0 - 2.5	7
	7	2/80	1.5	0.8 - 2.5	4
	8	2/80	1.7	0 - 3.6	4
	9	2/80	2.3	0.8 - 4.4	4
	10	2/80	0.6	0 - 0.9	3
	11	2/80	3.4	0 - 6.8	3
	16	8/79	0.8	0 - 2.6	7
	17	8/79	1.8	0.9 - 3.6	7
	19	9/81	1.5	0 - 3.1	5
	20	9/81	1.4	0.6 - 1.9	5
	21	9/81	3.0	0 - 8.5	5
	22	9/81	3.5	0.6 - 9.0	5
U.S. Steel, Fairfield[27]	9	6/79	0.3	0 - 1.7	6

Average
1.6

APPENDIX E:
EXAMPLE COKE OVEN
EMISSION CALCULATIONS

EXAMPLE CALCULATIONS FOR COKE OVEN EMISSION RATES

From AWMA

H_2S = 0.24 g/h/leak
BSO = 0.2 g/h/leak

@ 3 minutes of uncontrolled charging BSO = 0.05 kg/Mg coal
@ 30 PLD BSO = 0.13 kg/Mg coal
@ 20 PLL/PLO BSO = 0.002 kg/Mg coal

Scaling everything relative to BSO

@ 3 minutes of uncontrolled charging H_2S = 0.06 kg/Mg coal
@ 30 PLD H_2S = 0.156 kg/Mg coal
@ 20 PLL/PLO H_2S = 0.0024 kg/Mg coal

Instantaneous Emission Rates for H_2S for a poorly controlled battery:

assumptions

3 minutes of uncontrolled charging emissions
30% leaking doors (PLD)
20% leaking lids or offtakes (PLL/PLO)
62 ovens with 2 doors each
16.3 Mg coal/oven
18 hour cycle time

Charging (1 oven charged at a time)

0.06 kg/Mg coal * 16.3 Mg coal/oven / 3 minutes/charge / 60 s/minute * 1000 g/kg * 1 oven/battery
= 5.43 g/s/battery

Doors

0.156 kg/Mg coal * 16.3 Mg coal/oven * 62 ovens/battery / 18 hours / 3600 s/hour * 1000 g/kg
= 2.43 g/s/battery

Lids/Offtakes

0.0024 kg/Mg coal * 16.3 Mg coal/oven * 62 ovens/battery / 18 hours / 3600 s/hour * 1000 g/kg
= 0.037 g/s/battery

One Hour Average H_2S Emission Rates for a Battery Operating at MACT Limits

Charging

For a battery with 3 minutes of uncontrolled charging, one hour average emissions are:

5.43 g/s/battery * 180 seconds/charge * 8 charges/hour / 3600 s/hour
= 2.17 g/s

From U.S.EPA 1987:
Mass emissions are proportional to the square of the number of seconds per charge

Therefore $2.17 \text{ g/s} = x * (180)^2$
$x = 6.708 \times 10^{-5}$
and at 12 s/charge
$y = 6.708 \times 10^{-5} * 12^2$
$y = 0.01$ g/s

Doors

From U.S.EPA 1987:

Mass emissions $= z * (PLD)^{2.5}$; PLD > 10

@ 30 PLD the mass emissions are 2.43 g/s ; z = 0.0005

Mass emissions $= 0.0005 * (PLD)^{1.5}$; PLD < 10

@ 5.5 PLD the mass emissions are 0.006 g/s (differences with tables in report are due to rounding errors)

Lids and Offtakes

PLL/PLO are linearly related to mass emissions

@ 20 PLO mass emission = 0.037 g/s

@ 3 PLO mass emissions = 0.006 g/s

APPENDIX F:
U.S. EPA 1987 - COSTS
FOR COKE OVEN BATTERIES

TABLE 8-3. COST DATA FROM ARMCO, INC.[6]

Plant: Armco, Inc., Middletown, OH

Battery:	1	2	3
Type:	Wilputte	Still	Still
Height (M):	4	6	6
No. ovens:	76	57	57
Mains:	2	2	2
Capacity (1,000 Mg/yr):	448	664	664

	Item description (battery No.)	Unit cost	Unit	Year	Index	1984 $
1.	Additional labor for doors (person per shift) (1)	120,000	Battery-yr	1984	-	120,000
2.	Additional labor for doors (2, 3)	None	-	-	-	-
3.	Door repair costs (1)	295,000	Battery-yr	1984	-	295,000
4.	Door repair costs (2, 3)	293,000	Battery-yr	1984	-	293,000
5.	Spare doors--8 (1)	16,000	Each	1984	-	16,000
6.	Spare doors--16 (2 3)	25,000	Each	1984	-	25,000
7.	Replace chuck doors	400	Each	1984	-	400
8.	Door test program (2, 3)	300,000	2 batteries	1984	-	300,000
9.	End closure modifications (2, 3):					
	Jambs	2,989,000	2 batteries	1984	-	2,989,000
	Lintels	27,000	2 batteries	1984	-	27,000
	Protective castings	33,000	2 batteries	1984	-	33,000
	Fab. doors	226,000	2 batteries	1984	-	226,000
	Spare doors	87,000	2 batteries	1984	-	87,000
	Oven doors	1,784,000	2 batteries	1984	-	1,784,000
	Buckstay plates	43,000	2 batteries	1984	-	43,000
	Install plates	470,000	2 batteries	1984	-	470,000
	Inspection stations	140,000	2 batteries	1984	-	140,000
	Door cleaners	666,000	2 batteries	1984	-	666,000
	Jamb cleaners	200,000	2 batteries	1984	-	200,000
	Event recorders	39,000	2 batteries	1984	-	39,000
	Subtotal	6,704,000	2 batteries	1984	-	6,704,000
	Engineering	120,000	2 batteries	1984	-	120,000
	Contingency	634,000	2 batteries	1984	-	634,000
	Total	7,458,000	2 batteries	1984	-	7,458,000

TABLE 8-3 (continued)

Item description (battery No.)	Unit cost	Unit	Year	Index	1984 $
10. Additional topside labor, 2/shift (1)	240,000	Battery-yr	1984	-	240,000
11. Additional topside labor, 1/shift (2, 3)	120,000	2 batteries-yr	1984	-	120,000
12. Offtake modifications (2, 3)	1,100,000	2 batteries	1984	-	1,100,000
13. Offtake modifications (2, 3)	4,725	Each	1984	-	4,725
14. New standpipe caps (1)	11,700	Battery	1984	-	11,700
15. New standpipe caps (1)	77	Each	1984	-	77
16. Stage charging modifications (1)	373,000	Battery	1979	1.3[c]	485,090
17. Engineering study (1)	179,000	Battery	1979	1.7[d]	304,000
18. Development of procedures, all workers	50,000	3 batteries	1984	-	50,000
19. Worker training (1, 2, 3), all workers	216	Worker-yr	1984	-	216
20. Worker training (1)	10,800	Battery-yr	1984	-	10,800
21. Worker training (2, 3)	16,200	2 batteries-yr	1984	-	16,200
22. Askania modifications (2, 3)	14,700	2 batteries	1984	-	14,700
23. Monitoring, all coke plant sources	8,000	3 batteries-yr	1984	-	8,000

Note: For the footnotes to the indices see Table 8-5.

TABLE 8-4. ARMCO COSTS FOR TWO NEW 6-METER BATTERIES[6]

	Item description	Unit cost	Unit	Year	Index	1984 $
1.	114 extra standpipes and goosenecks*	1,023,218	2 batteries	1978	1.4[h]	1,430,000
2.	Extra main, crossovers, valves, bleeders*	1,333,872	2 batteries	1978	1.4[h]	1,870,000
3.	Steam piping, emergency water system	513,777	2 batteries	1978	1.4[h]	719,000
4.	Heavier buckstays, tie rods, springs	142,800	2 batteries	1978	1.4[h]	200,000
5.	Larry car modifications	1,309,002	2 batteries	1978	1.4[h]	1,830,000
6.	Engineering for larry car modifications	178,500	2 batteries	1978	2.0[i]	357,000
7.	Additional row of charging holes	61,625[†]	2 batteries	1978	1.4[h]	86,300
8.	Modified charging holes and lids	79,300[†]	2 batteries	1978	1.4[h]	111,000
9.	Modified goosenecks	74,375	2 batteries	1978	1.4[h]	104,000
10.	Coal bin modifications	476,001	2 batteries	1978	1.4[h]	666,000
11.	Increased cost of 2 cokeside door machines	595,001	2 batteries	1978	1.4[h]	833,000
12.	Engineering for door machines and coke guides	118,999	2 batteries	1978	2.0[i]	238,000
13.	Reinforcement for heavier equipment for doors	386,751	2 batteries	1978	1.4[h]	541,000
14.	Two pusher machines	2,142,003	2 batteries	1978	1.4[h]	3,000,000
15.	Engineering for pusher machines	178,500	2 batteries	1978	2.0[i]	357,000
16.	Brickwork, door, and jamb modifications	2,570,403	2 batteries	1978	1.4[h]	3,600,000
17.	Door seals, beefed up design	538,595	2 batteries	1978	1.4[h]	754,000
18.	8 spare doors	77,474	2 batteries	1978	1.4[h]	108,000
19.	Heavier, wider jambs	207,606	2 batteries	1978	1.4[h]	291,000
20.	Oven armouring	1,529,259	2 batteries	1978	1.4[h]	2,140,000
21.	More expensive foundation	327,250	2 batteries	1978	1.4[h]	458,000
22.	Door repair areas	521,615	2 batteries	1978	1.4[h]	730,000
23.	Increased instrumentation	222,520	2 batteries	1978	1.4[h]	312,000
24.	Tar and flushing liquor system for second main	2,149,085	2 batteries	1978	1.4[h]	3,008,000
25.	Coal mixing and density control	290,700	2 batteries	1978	1.4[h]	407,000

Note: For the footnotes to the indices see Table 8-5.

*Also includes flushing liquor piping, regulating house and regulators, walkways, stairs, platforms, supports, pitch traps.

TABLE 8-6. CHARGING COSTS AT EMPIRE COKE

Plant: Empire Coke, Holt, AL
Battery: 1, 2
Description: 60 ovens, foundry coke, single main, 160,600 Mg/yr

A. Charging costs--major capital items

Item	$1,000
Basic stage charging system	794
Develop procedures	2.2
Aspiration system, jumper pipes	20
Larry car modifications	18
Leveler smoke boot	6.5
Engineering study	178
Battery modifications[a]	930
Repave oven top	12
Total	1,960

B. Annual costs

Item	$1,000/yr
Inspect, clean goosenecks	3.1
Inspect, clean standpipes	1.6
Inspect, clean steam nozzles	10.8
Inspect, clean roof carbon[b]	0-1.7
Inspect, clean liquor sprays[b]	0-10.6
Training program	1.0
Monitoring[c]	5.0
Increased steam[d]	34
Capital recovery[e]	174
Total	230-242
$/oven-yr	3,800-4,000
$/Mg	1.43-1.51

[a]Includes replacing collecting main, modifying coal belt, installing a weigh scale, and extending larry car tracks.

[b]Assumes 0 to 100 percent attributable to baseline regulations.

[c]Assumes 50 percent of plant total is for charging.

[d]Estimated as $0.21/Mg coke.

[e]Capital recovery factor = 0.0886 (20 years at 6.2 percent).

TABLE 8-7. CHARGING COSTS FOR ARMCO'S WILPUTTE BATTERIES

Plant: Armco, Inc., Middletown, OH
Battery: 1
Description: 76 ovens, double main, 448,000 Mg/yr

A. Charging costs--major capital items

Item	$1,000
Stage charging modifications	485
Engineering study	304
Development of procedures[a]	8.5
Total	797.5

B. Annual costs

Item	$1,000/yr
Additional labor[b]	120
Worker training[a]	5.4
Monitoring[a]	1.3
Steam[c]	94
Capital recovery[d]	70.7
Total	291
$/oven-yr	3,800
$/Mg	0.65

[a]Assumes 50 percent of plant total is for charging.

[b]Assumes 1 of 2 additional people per shift on topside added for charging control (lid removal, replacement, gooseneck inspection and cleaning).

[c]At $0.21/Mg coke.

[d]Capital recovery factor = 0.0886 (20 years at 6.2 percent).

TABLE 8-5. CHARGING COSTS FOR ARMCO'S TALL BATTERIES

Plant: Armco, Inc., Middletown, OH
Battery: 2, 3
Description: 57 6-m ovens each, 604,000 Mg/yr each

A. Charging costs--major capital items

Item	$1,000
Larry car modifications	1,830
Engineering	357
Modified charging holes and lids	111
Modified goosenecks and standpipes	104
Coal mixing and density control	407
Leveler bar seal	213[a]
Second collecting main and accessories[b]	0-1,870
Extra standpipes and goosenecks[b]	0-1,430
Askania modifications	15
Development of procedures[c]	17
Total	3,054-6,354

B. Annual costs

Item	$1,000/yr
Worker training[c]	8.1
Monitoring[c]	2.7
Steam[d]	279
Labor[e]	60
Capital recovery[f]	271-563
Total	621-913
Per battery-yr	311-457
$/oven-yr	5,400-8,000
$/Mg	.47-0.69

[a]Derived from Bethlehem Steel questionnaire.

[b]Assumes 0 to 100 percent attributable to baseline regulations.

[c]Assumes 50 percent of the plant total is for charging.

[d]At $0.21/Mg coke.

[e]Assumes one-half of additional topside labor for charging (lid removal, [illegible], gooseneck inspection and cleaning).

[f]Capital recovery factor = 0.0886 (20 years at 6.2 percent).

TABLE 8-9. CHARGING COSTS FOR BETHLEHEM STEEL

Plant: Bethlehem Steel, Sparrows Point, MD
Battery: 1, 11
Description: Battery 1 has 63 ovens, single main, 273,000 Mg/yr.
Battery 11 has 65 ovens, double main, 363,000 Mg/yr.

A. Charging costs--major capital items

Item	$1,000	
	1	11
Larry car modifications	850	850
Improved aspiration system	448	448
Leveler bar seal	213	213
Repave battery top	-	750
Jumper pipe	5	-
Engineering study	Included in above items	
Total	1,516	2,261

B. Annual costs

Item	$1,000/yr	
	1	11
Inspect, clean goosenecks	70	70
Inspect, clean steam nozzles	25	25
Inspect, clean liquor sprays[a]	0-25	0-25
Monitoring[b]	2.8	2.8
Steam[c]	57	77
Capital recovery[d]	134	200
Total	280-314	375-400
$/oven-yr	4,600-5,000	5,800-6,200
$/Mg	1.06-1.15	1.03-1.10

[a]Assumes 0 to 100 percent is attributable to baseline regulations.

[b]Assumes 50 percent of plant total is for charging.

[c]At $0.21/Mg coke.

[d]Capital recovery factor = 0.0886 (20 years at 6.2 percent).

TABLE 8-10. CHARGING COSTS FOR U.S. STEEL AT CLAIRTON

Plant: U.S. Steel, Clairton, PA
Battery: 2, 20, 21
Description: Battery 2 has 64 ovens, double main, 300,000 Mg/yr.
Batteries 20, 21 each have 87 ovens, double main, 535,000 Mg/yr

Cost estimate	Battery 2	Battery 20
Annual cost ($1,000/yr)	377-436	425-485
$/oven-yr	5,900-6,800	4,900-5,600
$/Mg	1.26-1.45	0.79-0.91

TABLE 8-12. DOOR CONTROL COSTS FOR EMPIRE COKE

Plant: Empire Coke, Holt, Al.
Battery: 1, 2
Description: 60 ovens; hand-luted doors; 160,600 Mg coke/yr

A. Door costs

Item	Range ($1,000/yr)
Inspect and clean doors[a]	3.7-7.3
Labor to lute doors[a,b]	27.5-55.0
Labor to mix luting material[a,b]	11.7-23.4
Cost of luting material[a,b]	9.0-18.0
Monitoring[c]	2.5
Total	54.4-106.2
$/oven-yr	910-1,800
$/Mg	0.34-0.66

[a]Assumes 50 to 100 percent of plant total is attributable to baseline regulations.

[b]Assumes 90 percent of total luting costs are for doors and 10 percent for topside.

[c]Assumes 25 percent of total monitoring is for door leaks.

TABLE 8-13. DOOR CONTROL COSTS FOR ARMCO'S WILPUTTE BATTERY

Plant: Armco, Inc., Middletown, OH
Battery: 1
Description: 76 4-m ovens, self-sealing doors, 448,000 Mg/yr

A. Door costs - major capital items

Eight additional spare doors at $16,000 each or $128,000 total.

B. Annual door costs

Item	$1,000/yr
Door repairs[a]	150-295
Additional labor[b]	120
Worker training[c]	1.1
Monitoring[c]	0.7
Capital recovery[d]	11
Total	283-428
$/oven-yr	3,700-5,600
$/Mg	0.63-0.96

[a]Assumes 50 to 100 percent attributable to baseline regulations.

[b]Assumes 10 percent of plant total is for doors.

[c]Assumes 25 percent of plant total is for doors.

[d]Capital recovery factor = 0.0886 (20 years at 6.2 percent).

TABLE 8-14. DOOR CONTROL COSTS FOR ARMCO'S 6-m BATTERIES

Plant: Armco, Inc., Middletown, OH
Battery: 2, 3
Description: 6-m Carl-Still, 57 ovens each, 664,000 Mg/yr each.

A. Door costs--major capital items

Item	$1,000
Door test program	300
Spare doors[a]	400
End-closure modifications[b]	0-7,500
	700-8,200

B. Annual costs

Item	$1,000/yr
Door repairs[c]	293-585
Additional labor	None
Worker training[d]	2.2
Monitoring[e]	1.4
Capital recovery[f]	62-727
Total	359-1,320
$/oven-yr	3,100-11,600
$/Mg	0.27-0.99

[a]16 additional spare doors at $25,000 each.

[b]Assumes 0 to 100 percent attributable to baseline regulations.

[c]Assumes 50 to 100 percent attributable to baseline regulations.

[d]Assumes 10 percent of plant total is for doors.

[e]Assumes 25 percent of plant total is for doors.

[f]Capital recovery factor = 0.0896 (20 years at 6.2 percent).

TABLE 8-15. DOOR CONTROL COSTS FOR BETHLEHEM STEEL

Plant: Bethlehem Steel, Sparrows Point, MD
Battery: 1, 11, A
Description: Battery 1 has 63 3-m ovens, hand-luted doors, 273,000 Mg/yr.
Battery 11 has 65 3.5-m ovens, self-sealing doors, 365,000 Mg/yr.
Battery A is a new 6-m, 80 ovens, self-sealing doors, 1,148,000 Mg/yr

A. Door costs--major capital items

Item	$1,000		
	1	11	A
Install NiCuTi door seals[a]	-	190	-
Original door seals[b]	-	-	0-220
Spare doors[c]	24	26	32
	24	216	32-252

B. Annual door costs

Item	$1,000/yr		
	1	11	A
Operate, service all ovens and door repair facility[d]	105-210	108-215	132-264
Monitoring[e]	1.4	1.4	1.4
Capital recovery[f]	2.1	19.0	2.8-22
Total	109-214	129-235	136-287
$/oven-yr	1,700-3,400	2,000-3,600	1,700-3,600
$/Mg	0.40-0.78	0.35-0.64	0.12-0.25

[a] $1,450 each.

[b] Assumes 0 to 100 percent attributable to baseline regulations at $1,400 each.

[c] Assumes 5 percent extra for spares at $4,000 each (from Table 8-2) to maintain spares.

[d] Assumes 50 to 100 percent is attributable to baseline regulations at $3,300/oven-yr.

[e] Assumes 25 percent of plant total is for doors.

[f] Capital recovery factor = 0.0886 (20 years at 6.2 percent).

TABLE 8-16. DOOR CONTROL COSTS FOR U.S. STEEL AT CLAIRTON

Plant: U.S. Steel, Clairton, PA
Description: Batteries 1, 2, 7 have 64 ovens, 296,000 Mg/yr; Battery 17 has 61 ovens, 302,000 Mg/yr; Batteries 19, 20, 21 have 87 ovens, 530,000 Mg/yr; Battery 8 is a new 6-m with 75 ovens and 804,000 Mg/yr.

Cost estimate	Battery number			
	1,2,7	17	19,20,21	8
Annual cost ($1,000/yr)	230	283	311	269-287
$/oven-yr	3,600	4,600	3,600	3,600-3,800
$/Mg	0.78	0.94	0.59	0.33-0.36

TABLE 8-19. TOPSIDE LEAK CONTROL COSTS FOR EMPIRE COKE

Plant: Empire Coke, Holt, AL
Battery: 1, 2
Description: 60 ovens; 3 lids and 1 offtake per oven; 160,600 Mg/yr

A. Topside leak control costs[a]

Item	$1,000/yr Lids	$1,000/yr Offtakes
Luting labor[b]	17.3-34.5	5.8-11.5
Maintain slip joint seal	-	1.3
Inspect, clean, repair lids[b]	1.6-3.1	-
Labor to mix luting material[b,c]	1.0-2.0	0.3-0.7
Cost of luting material[b,c]	.8-1.5	0.3-0.5
Monitoring[d]	1.3	1.3
Total	22-42.4	9.0-15.3
$/oven-yr	370-710	150-260
$/Mg	0.14-0.26	0.06-0.10

[a]Labor items applicable to both lids and offtakes are split 75/25 percent (3 lids and 1 offtake).

[b]Assumes 50 to 100 percent is attributable to baseline regulations.

[c]Assumes 10 percent of plant total is for topside leak control (90 percent for luted doors).

[d]Assumes 25 percent of plant total is for topside leaks and divided evenly between lids and offtakes (one traverse for each).

TABLE 8-20. TOPSIDE LEAK CONTROL COSTS FOR ARMCO, INC.

Plant: Armco, Inc., Middletown, OH
Battery: 1, 2, 3
Description: (1) 76 ovens, 3 lids and 2 offtakes per oven, 448,000 Mg/yr; (2, 3) 57 ovens each, 6-m height, 4 lids and 2 offtakes per oven, 664,000 Mg/yr each.

A. Topside capital costs[a]

	$1,000			
	1		2, 3	
Item	Lids	Offtakes	Lids	Offtakes
Replace offtake system	-	-	-	1,100
Replace standpipe caps	-	11.7	-	-
Develop procedures[b]	2.5	1.7	5.7	2.8
Total	2.5	13.4	5.7	1,103

B. Annual costs[a]

	$1,000/yr			
	1		2, 3	
Item	Lids	Offtakes	Lids	Offtakes
Additional topside labor[c]	72	48	40	20
Monitoring[c,d]	0.4	0.4	0.7	0.7
Training[c,d]	1.4	1.4	2.1	2.1
Capital recovery[e]	0.2	1.2	0.5	98
Total	74	51	43.3	120.8
$/oven-yr	970	670	380	1,100
$/Mg	0.17	0.11	0.03	0.09

[a] Items applicable to both lids and offtakes are split 60/40 percent for Battery 1 and 67/33 percent for Batteries 2 and 3.

[b] Assumes 25 percent of plant total is for topside leaks.

[c] Assumes one-half of additional labor is for topside leaks and one-half for charging.

[d] Training and monitoring costs are divided evenly between lids and offtakes.

[e] Capital recovery factor = 0.0886 (20 years at 6.2 percent).

TABLE 8-21. TOPSIDE LEAK CONTROL COSTS FOR BETHLEHEM STEEL

Plant: Bethlehem Steel, Sparrows Point, MD
Battery: 1, 11, A
Description: (1) 63 ovens, 4 lids and 1 offtake per oven, 273,000 Mg/yr;
(11) 65 ovens, 4 lids and 2 offtakes per oven, 365,000 Mg/yr;
(A) 80 6-m ovens, 4 lids and 2 offtakes per oven, 1,148,000 Mg/yr.

A. Topside leak control costs[a]

Item	$1,000/yr					
	1		11		A	
	Lids	Offtakes	Lids	Offtakes	Lids	Offtakes
Topside luting[b]	38.4-76	9.6-19	32-63.3	16-31.7	34-68	17-34
Maintain slip joint seal[c]	-	18-35	-	18-35	-	13-26
Monitoring[d]	0.7	0.7	0.7	0.7	0.7	0.7
Total	39.1-76.7	28.3-54.7	32.7-64.0	34.7-67.4	34.7-68.7	30.7-60.7
$/oven-yr	620-1,200	450-870	500-980	530-1,000	430-860	380-760
$/Mg	0.14-0.28	0.08-0.15	0.09-0.18	0.10-0.18	0.03-0.06	0.03-0.05

[a]Items applicable to both lids and offtakes are split 20/80 percent for Battery 1 and 67/33 percent for Batteries 11 and A.

[b]Assumes 50 to 100 percent of cost is attributable to baseline regulations.

[c]Assumes slip joint maintenance is 25 to 50 percent of the total for inspecting, cleaning, and repairing offtakes.

[d]Assumes 25 percent of plant total is for topside leaks and cost is evenly divided between lids and offtakes.

TABLE 8-22 TOPSIDE LEAK CONTROL COSTS FOR U S. STEEL AT CLAIRTON

Plant: U S Steel, Clairton, PA
Battery: 2, 20, 21, 8
Description (2) 64 ovens, 4 lids and 2 offtakes per oven, 300,000 Mg/yr;
(20, 21) 87 ovens, 4 lids and 2 offtakes per oven, 535,000 Mg/yr;
(8) 75 6-m ovens, 4 lids and 2 offtakes per oven, 804,000 Mg/yr.

Cost estimate	Battery 2		Battery 20		Battery 21		Battery 8	
	Lids	Offtakes	Lids	Offtakes	Lids	Offtakes	Lids	Offtakes
Annual cost ($1,000/yr)	88.5-173	138-180	96-188	183-229	96-188	183-229	39-73	5 8
$1,000/oven-yr	1.4-2.7	2.2-2.8	1 1-2.2	2 1-2.6	1.1-2.2	2.1-2.6	0.5-1.0	0.1
$/Mg	0.30-0.58	0.46-0.60	0.18-0.35	0.34-0.43	0.18-0 35	0 34-0 43	0 05-0.09	0.01